

REPORT
OF THE
Geological Survey
of Ohio

VOLUME VIII.

COMPRISING REPORTS ON VARIOUS
MINERAL INDUSTRIES.

PUBLISHED, BY AUTHORITY OF THE LEGISLATURE OF OHIO,
UNDER THE SUPERVISION OF
EDWARD ORTON, JR., STATE GEOLOGIST.

COLUMBUS, OHIO, JANUARY, 1906.

LETTER OF TRANSMITTAL.

To His Excellency, JOHN H. PATTISON, Governor of Ohio:

SIR: — I have the honor to present to you Volume VIII of the Reports of the Geological Survey of Ohio. It consists *First*, of a Preface, dealing with the organization of the survey, the laws under which it operates, its property and equipment, its publications, and its financial transactions, and *Second*, of three bulletins which have been prepared and published under my supervision, as follows:

Bulletin I. On the Occurrence and Exploitation of Petroleum and Natural Gas in Ohio, by Professor John Adams Bownocker, D. Sc.

Bulletin II. The Use of Hydraulic Cements, by Professor Frank Harvey Eno, C. E.

Bulletin III. The Manufacture of Hydraulic Cements, by Professor Albert Victor Bleininger, B. Sc.

These Bulletins have been issued singly as soon as published, according to the law, and their enthusiastic reception and continued sale has shown that they have met a popular and scientific need. They have therefore to some extent demonstrated the wisdom of the policy upon which the Survey has been operating and justified the expense to which the state has been put in preparing and publishing them.

They are now put into this volume, as provided by the law, to bring them into a permanent form which shall be in harmony with the previous reports of the Survey.

Very respectfully submitted,

EDWARD ORTON, JR.,
State Geologist.

Ohio State University, January, 1906.

PREFACE.

By **PROF. EDWARD ORTON, Jr., STATE GEOLOGIST.**

THE ORGANIZATION AND WORK OF THE GEOLOGICAL SURVEY OF OHIO.

In issuing this volume, the first of a new series, it is proper and seasonable to set forth the relation of the work here presented with that which has been done by the organization in previous years, and to state what plans for the future are now being entertained.

HISTORICAL.

The last work done by the survey under the administration of Dr. Edward Orton, was embodied in Volume VII, published in 1893. In that volume, the preface, amounting to 11 pages, was devoted to a historical review of the work accomplished up to that time by the First, Second and Third organizations of the Geological Survey of Ohio. It is there shown that in Volume VII, the last outstanding tasks were completed, the last unpublished manuscript collected, the promises made during preceding administrations fulfilled, and that the volume thus brought to a natural conclusion the work which had been carried on for so many years.

During the succeeding six years, the work of the survey stood in abeyance. Dr. Orton still held the appointment of State Geologist, but the position was largely honorary as no appropriations were made to support the office in any way. Correspondence involving geological questions was answered and occasional visits were made to different points to give advice regarding local geological problems, but this work was done voluntarily and at private expense.

Dr. Orton's death occurred on October 16th, 1899, and Governor Bushnell appointed the present incumbent on December 4th, 1899, to fill out the unexpired term, which terminated April 22nd, 1901. At this time Governor Nash appointed the present incumbent for the term ending April 22nd, 1904, and later Governor Herrick reappointed him for the term ending April 22nd, 1907.

THE LEGAL STATUS OF THE SURVEY.

The law under which the last work of the Third organization was performed was passed in 1889. For the information of the public, it is published in full:

Laws of Ohio, 1889, Vol. 86, p. 262.

(Senate Bill 409.)

AN ACT

To provide for the extension of the Geological Survey of the State.

Section 1. Be it enacted by the General Assembly of the State of Ohio, That the governor is hereby authorized to appoint a state geologist, whose duty it shall be to continue and extend the investigations already made into the geological structure and resources of the state. Said state geologist shall be appointed for a term of three years, but he may be removed for cause at any time, and a successor appointed in his stead; and the governor is authorized to fill any vacancy which may occur from any cause, at any time. The compensation of said state geologist shall be at the rate of two hundred dollars per month, for the time actually employed; and said geologist shall have power to employ such assistants as he may need; but in no event shall the salary of the geologist, pay to assistants, and expense of the department, exceed the amount of the expenditure authorized by the general assembly.

Section 2. It shall be the duty of said geologist to study, and determine as nearly as possible, the number and extent of the various formations of the state; to represent the same, from time to time, upon properly constructed maps and diagrams; to study the modes of occurrence and the distribution of the useful minerals and products of these formations; to determine the chemical composition and structure of the same; to investigate the soils and water supply of the state; and to give attention to the discoveries of coal, building stone, natural cement, petroleum, gas and other natural substances of use and value to the state. He may also collect and describe the fossils of the various geological formations of the state; but no expenditure shall be incurred under this head that is not expressly ordered and provided for by the general assembly.

Section 3. The said geologist shall make, on or before the first day in February of each year, a report to the governor, covering the work of the preceding year, and the report shall be transmitted to the general assembly, to be printed in the same manner as other public documents, or as shall be otherwise ordered.

Section 4. The salaries of the state geologist, and the assistants employed by him, together with the traveling and incidental expenses, shall be paid monthly, on presentation of properly itemized vouchers, signed by the governor, out of the state treasury, from the appropriation made for such purpose.

Section 5. There is hereby appropriated from the general revenue fund the sum of one thousand dollars annually, for the purpose above named.

Section 6. This act shall take effect and be in force from and after its passage.

NOAH H. ALBAUGH,

Speaker pro tem. of the House of Representatives.

THEODORE F. DAVIS,

President pro tem. of the Senate.

Passed April 12, 1889.

From the terms of the law, it was evidently intended to provide for the creation of a bureau of geology to which only a portion of the time of the State Geologist should be applied, as the annual appropriation made was much too small to provide the salary of a State Geologist continuously,

without making any provisions for office expenses, assistance, etc. It was thought at that time that a few months' work per year would be sufficient to maintain the Survey abreast of geological developments.

The powers and duties of the State Geologist under this act were made so broad and general as to permit carrying on almost any work, so that no new legal provision was thought necessary in connection with re-opening the work of the survey under the Fourth organization. The sum designated in Section 5 is not made a limiting condition of the law, so that the Legislature may appropriate any other amount, at its discretion, for carrying on the work.

Acting under this law, the Legislature has made the following appropriations for geological work:

Designation of Legislature.	Year.	Amount Appropriated.
Seventy-Fourth	1900	\$2,500 00
Seventy-Fourth	1901	\$3,500 00
Seventy-Fifth	1902	\$5,000 00
Seventy-Fifth	1903	\$3,000 00
Seventy-Sixth	1904	\$2,800 00
Seventy-Sixth	1905	\$2,900 00

ORGANIZING THE SURVEY.

During the interval between the appointment of a State Geologist in 1899 and the appropriation of funds for the support of the Survey in 1900, the nature of the work to be undertaken, the equipment and property of the Survey left from the preceding administration, the men available for carrying on new work, and kindred matters were considered.

It was thought that the salient point of the geology of the state had been well worked out by the preceding organization, and the economic side of the question had been considered at much length. But neither science nor industry stand still, and in the decade or more which had passed since most of the work had been done, great changes had occurred. These

changes were principally in the interpretation placed upon the observed facts, rather than in the facts themselves. Some extensions had been made to discoveries formerly left incomplete, but in the main, the valid reason for again beginning work was to study anew the structure of the state and its mineral wealth from the point of view now prevailing. Further, while the people already had a good knowledge of the mineral resources of the state as to location and area, it was felt that much future work might profitably be directed towards increasing their knowledge of how to use them wisely.

On investigating the property of the Survey, it was found that it owned virtually nothing. A few levels and barometers in bad repair, and a few instruments for measuring the density of crude oil were all that could be found. A number of manuscript note books, containing data which had already been used in published reports were found and are carefully preserved.

In the line of publications, maps, volumes for distribution, etc., practically nothing was found. The Survey did not and does not now own one complete file of its own publications. The private set of the writer has so far been available, or it would have been necessary to purchase a complete set for the Survey long ago.

No volumes remained for distribution, except a few copies of Vol. VII, part 1, some two dozen sets of maps belonging to Vol. VII, a smaller quantity belonging to Vol. VI, and a few odd copies of other volumes and maps.

No desks, bookcases, or office furniture belonging to the Survey was left. The office had been administered by Dr. Orton either in his home or at the Ohio State University and no office equipment had ever been owned by the Survey.

From the foregoing it will appear that the work of organizing the Survey had to be undertaken, practically *de novo*. The Board of Trustees of the University were asked to give a room for an office, which they did in June, 1900. This room was equipped with desks, filing cases, and office furniture, which has been increased from time to time, until now the office is equipped for work and for the storage and preservation of its records.

The question of personnel of the Survey was considered. It was decided to create no permanent salaried positions for the technical staff and to proceed economically in the matter of office help. Accordingly, the officers of the Survey consist of the State Geologist, one clerk and stenographer (employed only half-time), and a variable and shifting corps of technical appointees, each of whom is detailed to make one special report. These technical assistants are employed on various terms: some at a salary per month, others at a per diem rate. No one has been paid for the writing of reports — only for the actual work of collecting the data.

Others have been paid a definite sum for a report, but always on a basis that would only afford a reasonable salary for field work, after traveling expenses had been deducted. These assistants are all appointed by the State Geologist and their work is under his supervision and control. They are not therefore state employees or appointments in the usual sense, as their position is more or less temporary according to the magnitude of the report which they may have been engaged to prepare.

The following is the complete roster of all persons who have held positions on the Survey from the beginning of its present organization to the present, including only those who have been employed in technical or executive capacities. Laborers and transient office help are not included.

EXECUTIVE.

EDWARD ORTON, JR., E. M. State Geologist
 METTA L. SEYMOUR. Clerk and Stenographer

TECHNICAL.

CHARLES SMITH PROSSER, M. Sc. Assistant Geologist
 Areal and Stratigraphical Geology.
 JOHN ADAMS BOWNOCKER, D. Sc. Assistant Geologist
 Economic Work in Oil, Gas, Salt and Coal.
 NATHANIEL WRIGHT LORD, E. M. Consulting Chemist
 Economic Work on Constitution and Utilization of Coals.
 ALBERT VICTOR BLEININGER, B. Sc. Special Assistant
 Technological Work in Cement Manufacture.
 SAMUEL VERNON PEPPEL, B. Sc. Special Assistant
 Technological Work in Lime and Sand Brick Industries.
 FRANK HARVEY ENO, C. E. Special Assistant
 Utilization of Portland Cement.
 ALICE GREENWOOD DERBY. Bibliographer
 Employed in making Subject Index of the Publications of the Survey.
 MARY WILSON PROSSER. Bibliographer
 Employed in making Bibliography of Ohio Geology other than the
 Publications of the Survey.
 MARION W. MUMMA, B. Sc. Assistant
 Employed in Mapping Trenton Limestone Oil and Gas Fields.
 RALPH W. NAUSS. Assistant
 Employed in Chemical Analysis of Cement Materials.
 BERTHOLD A. EISENLOHR. Assistant
 Employed in Collection of Coal Samples.
 EDWARD E. SOMERMEIER. Assistant
 Employed in Collection of Coal Samples.
 JESSE E. HYDE Assistant
 Employed in Mapping of Pittsburgh and Meigs Creek Coals,
 and in field work in Stratigraphical Geology.

Of these persons, Professors Prosser and Bownocker have been in continuous service since the survey was organized and have been at all times consulted in the policy of its management. All others have been in temporary connection only and have been consulted only regarding their own special tasks. In the cases of Messrs. Mumma, Nauss, Eisenlohr, Somermeir, and Hyde, the terms of employment have been short and the responsibility small. In the cases of Messrs. Eno, Bleininger, and Peppel, Miss Derby and Mrs. Prosser, each has prepared a bulletin or a portion of one, over his or her own signature. Prof. N. W. Lord has work in process of preparation.

INVESTIGATIONS COMPLETED AND IN PROGRESS.

FIRST. THE AREAL AND STRATIGRAPHICAL GEOLOGY OF OHIO.

The elaborate work done upon this topic in the seventies, and published in Volumes I, II and III, of the Survey Reports, was excellent at the time, but now needs revision. The work from 1882 to 1894 being economic, stratigraphical questions were only studied so far as necessary to tracing and classifying mineral deposits, so that the strata of Ohio were not classified according to the now accepted schemes, nor correlated with those of surrounding states, except where economic work made practical correlation necessary. Geologists from the United State Geological Survey, and from other states, were being sent into Ohio in order to find what light the rocks of this state would shed upon mooted points in stratigraphical work elsewhere.

Considerations of state pride as well as scientific enthusiasm both urged that this state should carry its own burdens and do its share in furthering researches into these purely scientific aspects of geology. Accordingly a small sum of money was set aside for this purpose and Mr. Charles S. Prosser, M. Sc., Professor of Geology in the Ohio State University, was appointed Assistant Geologist in charge of this topic.

Professor Prosser was unable to at once begin on Ohio work, as he had at the time unfinished researches in Kansas, Maryland and New York to complete and report upon for the United States Geological Survey or state surveys. But a beginning was made in 1900, and as these other tasks have from time to time been concluded, an increasing share of his time has been devoted to Ohio work, until it now receives almost the entire time he has available from University duties.

Professor Prosser has made a considerable headway in certain parts of the state. His first, Bulletin No. 7, on the Revised Nomenclature of the Ohio Geological Formations, appeared in December, 1905, and will take its place in Volume IX of this series.

In the nature of the case, Professor Prosser, working in the field during the summer vacation only, cannot expect or be expected to bring

out any complete or systematic treatise on the stratigraphy of the Ohio formations. To do so would require a number of persons employed all of the time, instead of one for two or three months per year, and would require several years under these conditions. Professor Prosser will present the results of his studies from time to time in Bulletin form. Each will be complete in itself and will attempt to settle definitely up to the present stage of knowledge the age and order of the formations discussed and the areas covered. It is the intention to continue, as means are available, to spend modest sums annually on this work as long as may be needed, publishing Bulletins from time to time when they are ready.

SECOND. THE OCCURRENCE AND EXPLOITATION OF PETROLEUM AND NATURAL GAS.

This topic has been previously carefully studied by the survey and elaborate reports were issued upon it in 1886, 1888 and 1890, presenting the facts then known. During the next ten years the industry continued to make rapid progress in extent and value of output. No further investigations were authorized until 1900, when the legislature again made appropriations for the work of the Geological Survey. This topic was considered as among the most urgent of all those presenting themselves for attention, and it was at once determined to bring the records of the discoveries and production of oil and gas down to date, while the facts were still available.

Accordingly, in June, 1900, I appointed Professor John Adams Bowditch, of the Ohio State University, to take up the study of this subject, and he pursued the same with great energy during the next three years. I submit the results of his labors with confidence that they will not only be found of great economic and scientific value at present, but also that their value will become increasingly apparent as time goes on. There seems good ground for believing that the supply of oil and gas is short-lived. It was discovered but a few decades ago, yet we have already witnessed the rapid exhaustion of many important fields. It becomes doubly important, therefore, that we shall preserve while we can the most complete and detailed records of its discovery and use. It is believed that the present report, in connection with those before issued, will accomplish these ends with credit to the state.

THIRD. THE USES OF HYDRAULIC CEMENT.

This topic, and the one following in item 4, represent most fairly the dominant idea which actuates the present management of the survey. The limestones, the lime industry, and the cement industry have all been written upon in the earlier reports. But, the point of view has so wholly changed, during the fifteen or twenty years since elapsed, that they fail to point out to the people of the state the value of their resources or the

possible strength as a cement producing state. A series of publications was therefore projected, of which this is one, to take up the whole subject *de novo*, and bring the matter to public attention in the light of modern industrial conditions.

The cement industry, as is well shown in Bulletin Three, is one of the most wonderful examples of the splendid virility of the American nation. In twenty years we have taken it up, perfected it, improved its manufacture, found new uses for it, and after supplying our own fabulously increasing needs, are beginning to look covetously upon the markets of the world, long occupied by the English and Germans. This story reads like a romance, and we little appreciate even now how wonderful an expansion yet lies ahead of us in the use of this supremely convenient and serviceable material.

The Geological Survey of Ohio has examined the cement industry before; a very valuable article on that subject appeared in Vol. VI, published in 1888, from the pen of Prof. N. W. Lord. But since that time the conditions have altered so fundamentally, that it was thought best to take the subject up and thoroughly discuss its present status.

Bulletin No. 2 is by Prof. Frank Harvey Eno, Associate Professor of Civil Engineering in the Ohio State University. Professor Eno has had much experience in the use of cements; he has laboriously searched the literature of the subject; he has traveled widely to visit and study the typical and important examples of all the uses to which cement is being put. He has, in accordance with my instructions, made this work a popular one — avoiding the symbols of the chemist or the mathematics of the engineer. He has written to reach the people — the great body on whose increasing intelligence in the use of cements depends the still greater expansion of the industry of the future.

While this bulletin is not the record of new and exhaustive researches in this field, at least to any important degree, and was not intended even to contain a detailed discussion of the many mooted points in the theory of cements, it must not be supposed that it is either loose in its statements or so general as to be of no value. It has been the aim to present the facts, with such few theoretical considerations as are now generally accepted, in such a simple and clear manner that it will be understood by all.

FOURTH. THE MANUFACTURE OF HYDRAULIC CEMENTS.

The task of studying and reporting upon the manufacture of hydraulic cements was given to Mr. Albert V. Bleining, at that time an assistant in the Department of Ceramics of the Ohio State University.

The marvelous expansion in recent years in hydraulic cement manufacture and the Portland cement industry, in particular, has resulted in a condition which is undesirable in several respects. Accurate information as to the nature of the raw materials best suited has not been available

and hence industries have been established at sites which are now known to be unfavorable, and where the local supplies must be rejected and others transported at a great permanent disadvantage if the output reaches a grade where its use is safe and proper. Also chemists whose training has been so directed as to give them facility in the class of problems here met are exceedingly scarce, and thus many plants have gotten into the way of running along with only the baldest daily essentials from the laboratory instead of asking and receiving from the chemist that class of information and advice which would enable them to rapidly conquer the obstacles and smooth away the difficulties which every new cement industry must inevitably face. Also, managers and directors of cement industries, not being able to obtain in any place a succinct statement of what has been done in this field of research, have sometimes adopted mistaken and dangerous policies as to their product, because the defects arising are mostly slow to develop and obscure, and have thus placed upon the market thousands of barrels of poor material whose use tends to discredit cements as a class, and prevent the superlative usefulness of good cements from being earlier and more fully recognized.

It has been my intent and desire in authorizing and supervising the preparation of a bulletin on this subject to place within the reach of every intelligent person who desires it a statement of what materials are needed to make good cements, of what mechanical treatment is necessary, and what effects will result from deviations from the prescribed quality of materials or treatment. It is not possible to convey these ideas without constant use of chemical nomenclature and chemical conceptions.

Mr. Bleininger's work is contained in this volume, as Bulletin No. 3.

It may be that the book will be a disappointment on this account to some persons who are interested in the industry, but who have not the training to readily grasp chemical conceptions. It has been written under the belief that the cement industry is really a branch of chemical engineering and that no one devoid of chemical and engineering training can be safely placed in control or high in the councils of this industry. To cement chemists, and managers of plants, the work will doubtless be readily accessible and it is hoped that the practical conclusions reached in all parts of the book will be available to all interested persons, whether the reasoning and investigations by which the conclusions are reached are equally clear or not.

I wish to record at this place my high appreciation of the work which Mr. Bleininger has put upon this volume. His search of the literature has been as thorough as his opportunities have afforded; his own laboratory researches have been most painstaking and laborious, and as a rule have been done by his own hands, in the intervals of his daily busy routine. His acquaintance with the various plants of the country is by no means confined to Ohio, as he covered the country in the course of his

studies. He has pursued his work at financial sacrifice to himself, which is the best evidence of his genuine devotion to the scientific work, which forms the last bulletin of this volume.

FIFTH. THE LIME RESOURCES OF OHIO, CONSIDERED ESPECIALLY FROM THE STANDPOINT OF CEMENT MANUFACTURE, BUT INCLUDING A STUDY OF THE TECHNOLOGY OF THE LIME INDUSTRY.

The preparation of a bulletin on the resources available for cement manufacture was necessary to the complete presentation of the subject taken up in Bulletins 2 and 3. The original intention was to confine the work to those lime deposits likely to be of value in the cement industry. But it was found that a study of the latter really involved a knowledge of all the lime resources.

The subject of the lime industry had been reported upon by Dr. Orton in 1888 in considerable detail and his work required but little editing to bring it up to date. Accordingly it was decided to go into the whole subject of the lime industry and bring it out as a bulletin, while all the time devoting special consideration to the cement resources and possibilities.

Also, the technology of lime burning and use had never been adequately studied, and an effort was made to present the facts in this connection with some considerable completeness. Special Assistant, Samuel V. Peppel, B. Sc., was given charge of this topic in connection with his collection of data for the cement resources, and has carried it out with much energy and enthusiasm. His completed report is now in press, and will be published as Bulletin 4, Chapters 5 and 6.

The first four chapters of Bulletin 4 deal with the occurrence of the lime resources, their sampling and composition and have been prepared by the State Géologist or jointly by the State Geologist and Mr. Peppel.

SIXTH. THE MANUFACTURE OF SAND-LIME BRICK.

This topic was also taken up in connection with the work of Bulletin 4, as it could be done easily in connection with it. The industry is a new one in this country, but has become well established in Germany, where upwards of one hundred plants are in successful operation. By this process, building brick of good grade are made from sand into which 5 to 10 per cent. of caustic lime has been thoroughly mixed. The mixture is shaped into bricks in powerful presses, and these are hardened in an atmosphere of steam for ten hours or more at high pressure. The process invites not only the use of lime on a large scale, but also opens the way to a still larger use for sand.

Mr. Samuel V. Peppel was also placed in charge of this work and has prepared a very excellent report on the subject, which will appear as Bulletin 5. Permission to publish in advance portions of this report in technical journals was given some time since, and these preliminary reports have attracted wide attention over the country.

Bulletins 4 and 5 will be bound in one cover as they are upon cognate subjects, and Bulletin 5 is of itself too small to make a permanently bound bulletin by itself.

SEVENTH. THE CHEMICAL CHARACTER OF OHIO COALS AND NOTES ON THEIR PROPER UTILIZATION.

This work was undertaken by Professor Nathaniel W. Lord, E. M., Consulting Chemist of the Survey, and Professor of Metallurgy in the Ohio State University, who has done a great deal of important work along this line in other connections. The coal veins studied so far comprise the No. 4 or Clarion (Ferriferous limestone) coal of Vinton, Jackson, Gallia and Lawrence counties, and the No. 6 or Middle Kittanning coal, which was sampled with unprecedented care at frequent intervals over its whole area between Athens and Tuscarawas counties. There yet remains the extreme northern and southern extensions of the No. 6 coal to be sampled, but the work now done covers the main productive area. These researches are directed towards establishing the chemical unity of real coal-matter of any particular vein, as distinguished from its accidental or accessory ash-forming ingredients, and also the sharp distinction between the real coal-matter of different veins, as evidenced by the composition, calorific power, etc. His work also includes a study of the occurrence of sulphur in coals, and to what extent it may be reduced by treatment.

Preliminary reports on part of this work have been published, by permission, in the engineering press. It is expected that a considerable portion of the report will be printed in the near future, but the completion of the work for all the coals of the state is a distant matter.

EIGHTH. THE SALT INDUSTRY OF OHIO.

This subject was taken up by Assistant Geologist Bownocker during the summer of 1903. The discovery and utilization of the rock salts of northern Ohio has all been subsequent to the report by W. J. Root in 1888, and the development of a growing soda ash industry on this foundation is the immediate occasion for taking it up at this time. Ohio with her stores of lime, sand and fuel, has only needed soda to become a great center of the glass industry. This supply has now become a possibility. The report on this topic is complete and ready for printing and will appear shortly as Bulletin 8.

NINTH. THE PITTSBURGH COAL IN HARRISON, AND THE MEIGS CREEK COAL IN HARRISON, JEFFERSON AND BELMONT COUNTIES.

Almost the only coal areas left unmapped in the work of the previous survey are those veins found in the high broken land of southeastern Ohio. The recent sudden increase in interest in the thin veins of coal away from present railroad communication has led to a very considerable

demand for information from this district. The topographical work of the United States Geological Survey which is being done in collaboration with the State of Ohio, has been practically completed in the area covered by these coals, and it is expected that the work will be greatly assisted by the new maps. Assistant Geologist Bownocker has this work in hand, but the report will not be completed without another season's field work. This concludes the list of topics upon which formal reports have been authorized.

PUBLICATIONS OF THE SURVEY.

The method of distribution of the reports of the Geological Survey has been the least efficient thing in connection with the work. The state has paid out large sums of money for the prosecution of the Survey. An able corps of scientists performed their tasks in a manner which has made their labors memorable. Their reports, while not up to the style of publication now in vogue, were well printed and well illustrated for the time when they appeared. But the state and people have not realized the full value of their investment, or rather have not realized as much from their investment as they could and should have done, on account of the system of distribution. This was not the fault of the officers of the Survey, as the matter was not placed in their hands. In all the early reports, the distribution of the whole issue was made at once; a small number, generally 400 or 500, were allotted to the State Geologist for his exchange list and free list. The balance of the issue was then distributed pro rata among the members of the Legislature who happened to be in office at the time. These persons, not having specially considered the question, were generally at a loss to know what to do with such large numbers of the reports. They were often used very unwisely — and seldom if ever did the allotment of a member reach a large percentage of interested persons.

This arrangement has also worked a great disadvantage to the Survey organization, from the fact that no supply was reserved for exchange or to supply the needs of libraries and collectors. Consequently, a short time after an issue was made, it was impossible to secure a copy in any official manner or from any official source, except as one happened to know some one who had been a member of the Legislature at the time.

With Volume V and subsequent volumes a new arrangement was made, by which the number distributed to the General Assembly was reduced, and a certain part of the issue was placed in the hands of the Secretary of State for sale at the cost of publication. This arrangement proved a great advance over the preceding method, but has proven still inadequate, as is shown by the fact that each issue thus put on the market was soon sold out.*

* A few copies of Vol. VII only are now left in the office of the Secretary of State.

FORMER PUBLICATIONS OF THE SURVEY.

The work performed by the First, Second and Third organizations of the Geological Survey of Ohio is comprehended in the following list of publications:

FIRST GEOLOGICAL SURVEY 1837-1838.

Title of Volume.	Date of Issue.	Number of Pages.	Number of Copies Printed.	Geologist in Charge.
First Annual Report.....	1838	134	5,000	
Second Annual Report.....	1838	236	5,000	W. W. Mather W. W. Mather

SECOND GEOLOGICAL SURVEY 1869-1888.

Title of Volume.	Date of Issue.	Number of Pages.	Number of Copies Printed.	Geologist in Charge.
Report of Progress.....	1869	176	14,500	J. S. Newberry
Report of Progress.....	1870	568	14,500	J. S. Newberry
Report of Progress.....	1871	3	400	J. S. Newberry
Geology of Ohio, vol. I, part I, Geology.....	1872	680	20,000	I. S. Newberry
Geology of Ohio, vol. I, part II, Paleontology.....	1873	*401 †49	20,000	J. S. Newberry
Geology of Ohio, vol. II, part I, Geology.....	1874	701	20,000	J. S. Newberry
Geology of Ohio, vol. II, part II, Paleontology.....	1875	*431 †59	20,000	J. S. Newberry
Geology of Ohio, vol. III, Geology.....	1878	958	20,000	J. S. Newberry
Geological Atlas of Ohio.....	1879		5,000	J. S. Newberry
Geology of Ohio, vol. IV, Zoology and Botany.....	1882	1,070	20,000	J. S. Newberry
Geology of Ohio, vol. V, Economic Geology.....	1884	1,124	10,000	Edward Orton
Preliminary Report on Petroleum and Inflammable Gas....	1886	76	2,500	Edward Orton
Geology of Ohio, vol. VI, Economic Geology.....	1888	831	15,000	Edward Orton

* Pages. † Plates.

THIRD GEOLOGICAL SURVEY, 1889-1894.

Title of Volume.	Date of Issue.	Number of Pages.	Number of Copies Printed.	Geologist in Charge.
First Annual Report.....	1890	323	10,000	Edward Orton
Geology of Ohio, vol. VII, part I, Economic Geology.....	1893	290	2,500	Edward Orton
Geology of Ohio, vol. VII, (complete including part I)....	1894	970	7,500	Edward Orton

OBTAINING COPIES OF THE OLD REPORTS.

First Geological Survey.— These volumes are out of print and rare. They can only be procured from dealers in second-hand libraries, and are difficult to obtain even there.

Second Geological Survey.— These volumes were all distributed at the time of their issue. The State retained no stock for meeting future demands, so that no copies of any of these volumes can be obtained from the office of the State Geologist. They can be bought in many second-hand book stores and from dealers in old libraries, at prices varying from a few cents to two or three dollars per volume, according to rarity and demand. Volumes V and VI are the rarest and most sought for.

Third Geological Survey.— These volumes were all distributed at the time of issue, except Volume VII, of which 1,500 were put in the hands of the Secretary of State, for sale at cost of publication. Of these, a few remain at the date of the publication of this volume. The price is \$1.50. To obtain copies, send postal or money order to the Secretary of State, State House, Columbus, O. No other volume can be obtained from this source.

The other volumes of this series can be procured only from second-hand book and library dealers.

THE PUBLICATION AND DISTRIBUTION OF THE PRESENT SERIES OF REPORTS.

Owing to the unfortunate situation in regard to the publications of the First, Second and Third organizations of the Geological Survey, it has been thought wise to designate the present series as the Fourth. There has been no legal enactment conferring a new title on the present organization of the survey, and, as already explained, the work is being done under the law of 1889, which marks the end of the second and the beginning of the third organizations. But a law has recently been enacted prescribing the method of publication and distribution of the reports of the State Geologist, which departs so far from the plans previously adopted that it makes such a differentiation in title of the bulletins necessary to the convenience of those who are to distribute and have charge of the future publications of the survey.

The text of the law is given herewith, as a matter of information to those interested.

Laws of Ohio, 1902, Vol. 95, p. 593.

(House Bill No. 800.)

AN ACT

To Provide for the Publication and Distribution of the Reports of the State Geologist.

Section 1. Be it enacted by the general assembly of the State of Ohio that whenever the state geologist shall have completed a bulletin upon any of the subjects upon which he is authorized to conduct investigation, he shall notify the state printing commission of this fact, and it shall be the duty of this commission to determine the number of copies which shall be printed, and the grade of paper, the kind of binding, and any other details incident to its proper publication.

Section 2. It shall be the duty of said commission to provide for the publication of said bulletin as soon as possible after the completion of the same. The issue shall consist of a minimum number of three thousand copies.

Of these, one thousand copies, after deducting 200 for the State Library, shall be distributed pro rata among the general assembly.

One thousand shall be distributed free by the state geologist in exchange with other surveys, and with individuals whose services have been used in collection or preparation of the matter for the bulletins. Of this number not more than four hundred may be distributed during the first year after publication, and not more than fifty in any subsequent year.

One thousand copies shall be set aside for binding with other bulletins from time to time, when a sufficient number of such bulletins have accumulated to make collectively a volume of from 800 to 1,000 pages. They shall be bound, lettered and numbered, to take their place in the series of volumes already published by the survey.

The distribution of the bound volume of the survey shall be in the hands of the state geologist; but the state library shall receive ten copies, each member of the general assembly one copy, with privilege to draw not to exceed two other copies on application, and public libraries in the state shall be supplied with one copy each. The volumes remaining after these demands have been met, may be distributed among the geological surveys and geological societies of the United States and of foreign countries, in exchange for their publications.

Section 3. The board may, at its discretion, order the publication of extra copies in addition to the three thousand already provided for. These extra copies shall be placed in the hands of the state geologist. From these, members of the general assembly may, on application, draw up to fifty (50) copies each. Those remaining shall be placed on sale at a price equal to the net cost of printing and binding, which price is to be established by the state supervisor of public printing. The proceeds of such sales shall be accounted for and paid into the state treasury, and the state geologist shall be required by the commission to give suitable bond for the security of the funds thus passing through his hands. The proceeds of such sales shall be credited to the account of the geological survey and shall be used for the prosecution of the further work of the survey without distinction from other funds which the general assembly from time to time appropriates for the survey.

Section 4. The cost of printing, illustrating, electrotyping, binding, et cetera, of said bulletins and said volumes, shall be paid from the general appropriation for state printing.

Section 5. This act shall take effect from and after its passage.

W. S. McKINNON,

Speaker of the House of Representatives.

F. B. ARCHER,

President of the Senate.

Passed May 12, 1902.

Under the terms of this act, a number of things have been accomplished which remedy, in large part, the weak points of the earlier systems.

(a) It provides for a minimum issue, for bulletins of small general interest, and an elastic system for increasing the issue, where bulletins promise to be of wide general interest.

(b) It provides for an adequate system of exchanges by which the credit of the state may be maintained among other states and countries which publish similar literature.

(c) It prevents the immediate distribution of all the copies of any report, and thus safeguards the needs of the future.

(d) In the case of large issues, it enables any one interested to secure a copy of any bulletin on payment of a small sum.

(e) It insures that the bulk of each issue reaches only interested persons, as copies can only be obtained by application and generally by payment. It is estimated that only a small part of the issues of the early reports ever reached appreciative hands.

(f) It provides for the publication at any time of any report which may be ready, thus making the work up-to-date and effective, instead of requiring all articles to wait until a sufficient number are ready to collectively make a volume.

(g) It is a step toward making the work self-supporting.

In short, this law is doing much to place the work of the survey upon a much more effective, useful and creditable basis than ever before, and on a parity with that of other states.

PUBLICATIONS OF THE PRESENT SERIES OF REPORTS.

The following list of bulletins has been issued, or is in process of preparation. Under the law copies of these bulletins can be bought at the office of the State Geologist, at the cost of publication. Postal orders, money orders, express orders, checks, drafts or currency, must accompany orders. Stamps will not be received.

FOURTH GEOLOGICAL SURVEY 1899—

Title of Volume.	Date of Issue.	Number of Pages.	Number of Copies Printed.	Price.	Geologist in Charge.
Bulletin 1. Oil and Gas..	1903	320	8,000	\$0 65	Edward Orton, Jr
Bulletin 2. Uses of Cements	1904	260	6,000	0 30	Edward Orton, Jr

FOURTH GEOLOGICAL SURVEY 1899.—Concluded.

Title of Volume.	Date of Issue.	Number of Pages.	Number of Copies Printed.	Price.	Geologist in Charge.
Bulletin 3. Manf. of Cements	1904	392	4,000	0 50	Edward Orton, Jr
Bulletin 4. Lime Industry.	1906	* †	4,000	.....	Edward Orton, Jr
Bulletin 5. Sand Lime Brick	1905	* †	4,000	.....	Edward Orton, Jr
Bulletin 6. Bibliography.	1906	*	3,500	.....	Edward Orton, Jr
Bulletin 7. Stratigraphy..	1905	52	3,500	0 06	Edward Orton, Jr
Bulletin 8. Salt.....	1906	*	.....	.....	Edward Orton, Jr

* In press. Price not yet determined.

† Bull. 4 and 5 will be bound in one cover, and only sold together.

LIBRARY OF THE SURVEY.

A well-equipped geological library is becoming a constantly increasing need in the doing of creditable work by the Survey. In 1904, the library consisted of less than a hundred reports and pamphlets, which had been sent in voluntarily by the surveys of other states and foreign countries. These had accumulated during the preceding four years. No effort had been made to form a regular exchange list, because the Ohio Geological Survey had nothing remaining from former issues which could be offered in exchange. When a new series of bulletins was ready for issue it seemed a proper time to take up seriously the question of exchange lists and the accumulation of a library.

The library of the Ohio State University, though not large, has been carefully selected, and has the nucleus of a good collection of books on geology. The geological library of the late Dr. Edward Orton was preserved intact, and has been presented to the University. It was thought a highly desirable thing if the reports and pamphlets received by the Survey in exchange for its own publications could also be deposited in the same place.

The chief obstacle heretofore to the Survey forming a library and accumulating geological exchanges has been in the lack of a definite method of caring for the books and pamphlets when received. The lack of a fixed office increased this difficulty. This last obstacle being removed, the foregoing facts were presented to the seventy-sixth general assembly, which passed the following resolution:

Seventy-Sixth General Assembly.
(Regular Session).

SENATE JOINT RESOLUTION NO. 22.

Relating to the Creation of a Depository for the Library of the Geological Survey of Ohio.

Be it resolved by the general assembly of the state of Ohio, that the state geologist is hereby authorized to enter into an agreement with the board of trustees of the Ohio State University by which the library of the Ohio State University is made the depository for the reports, books, pamphlets, maps, and manuscripts, acquired by exchange or otherwise, which constitute the library of the geological survey of Ohio; said agreement shall provide for the marking, accessioning, cataloging, shelving and ordinary care of said library; the terms upon which said library of the survey shall be available to the use of the students and faculty of the university; the terms upon which the library of the university shall be available for the use of the staff of the survey; and such other matters as the mutual interest and advantage of the two organizations may suggest; provided, that the state geologist shall have no power to permanently transfer the right and title to said library of the survey to the Ohio State University and also that any agreement made shall be without monetary consideration on either side.

GEORGE T. THOMAS,

Speaker of the House of Representatives.

WARREN G. HARDING,

President of the Senate.

Under the authority of the above resolution, the following agreement has been entered into between the Board of Trustees of the Ohio State University and the Ohio Geological Survey:

AGREEMENT BETWEEN THE BOARD OF TRUSTEES OF THE OHIO
STATE UNIVERSITY AND EDWARD ORTON, JR., STATE
GEOLOGIST OF OHIO.

WHEREAS, During the session of the 76th General Assembly the following joint resolution was regularly passed, viz:

(Resolution quoted above.)

Therefore, we, the Board of Trustees of the Ohio State University, party of the first part, and Edward Orton, Jr., State Geologist, acting for the Geological Survey, of Ohio, under the authority of the resolution above quoted, party of the second part, do hereby mutually agree as follows:

I.—That the party of the second part shall deposit in the custody of the Librarian of the party of the first part, all the books, pamphlets, maps, notes, and manuscripts now comprising the library of the Geological Survey of Ohio.

II.—That from time to time, where other books, maps, and pamphlets are secured by the Geological Survey of Ohio for its library, whether obtained by gift, exchange or purchase, they shall also be added to those already in the hands of the Librarian of the party of the first part.

III.—That the party of the second part reserves the right to any member of its corps to withdraw any part of the library thus deposited, for use in office or field, but where this is done the usual library receipt shall be taken for matter thus issued. Further, that nothing in this document shall be construed to mean:

or include the reports, bulletins, or other publications issued by the party of the second part, and which may be held for distribution, exchange or storage.

IV.—That the party of the second part agrees to spend annually such sums for the binding and repair of the books of the said Geological Library as may be necessary, or such part of the sum as the revenues of the Survey permit, but in event that he is unable to incur any such expenditures, then it shall be understood that the work shall remain undone.

V.—That the party of the second part agrees to permit the free use of its Geological library to the faculty, students and visitors of the Ohio State University on the same terms and subject to only the same restrictions as apply to the use of the Library of the Ohio State University.

VI.—That the party of the first part agrees to receive, house, shelve, list, catalog, mark, and otherwise care for the library of the party of the second part, and to put it with the least possible delay in condition for effective use, and to so maintain it during the time this agreement is in force, without any charge for the services thus performed but nothing in this section shall be interpreted to mean the expenditure of money for the binding and repair of the books and documents which are the property of the said party of the second part.

VII.—That the party of the first part agrees to permit the free use of its library to the corps of the party of the second part on the same terms and subject only to the same restrictions as apply to the use of this library by others.

VIII.—That the party of the first part agrees to keep the library of the party of the second part separate and independent from its own library, as to cases or shelves, as to catalogs or card indices, and as to marks or labels in the books, to the end that a separation of the two might easily be made in future without prejudice to the integrity of either, if this contract were nullified by a further act of the Legislature. Provided always, that the card catalog, shelf list and other necessary lists of the library of the party of the second part which may be prepared by the party of the first part shall become a part of said library and go with it in event of separation, and provided always, that nothing in the above section shall be construed to mean that the two libraries or portions thereof may not be kept in the same room or rooms for the greater convenience of their joint use.

IX.—It is the understanding and agreement between these contracting parties, that the arrangements thus entered into under the special authority of this act of the General Assembly of the State of Ohio, is not in the nature of an agreement which may be set aside hereafter by mutual consent, but that it will require to dissolve the same, an act of the General Assembly similar to that which made it possible at this time.

PAUL JONES,
President of the Board of Trustees.
ALEXIS COPE,
Secretary of the Board of Trustees.
EDWARD ORTON, JR.,
State Geologist.

Under the terms of the preceding contract, the books of the Survey have been turned over to the Library of the University and have been catalogued and put into shape for use.

Under the certainty that future accessions can be properly cared for, and conveniently used, the work of forming a regular exchange list with

other Geological Surveys and Scientific Societies has been taken up. If this policy of careful and business-like exchange is maintained and the lists increased as opportunity offers, the library of the Survey is certain to become an important one and of great service to its officers.

THE SURVEY IN ITS RELATION TO THE PUBLIC.

The usefulness of the Survey is not limited to the preparation of formal reports on important topics. There is a constant and insistent desire on the part of the people to use it as a technical bureau for free advice in all matters affecting the geology or mineral industries of the state. A very considerable correspondence comes in, increasing rather than decreasing in amount, and asking specific and particular questions on points in local geology.

The volume of this correspondence has made it necessary to adopt a uniform method of dealing with these requests. Not all of them can be granted, but some can and should be answered. There is a certain element of justice in the people demanding such information, from the fact that the geological reports issued in former years were not so distributed as to make them accessible to the average man or community to-day. The cases commonly covered by correspondence may be classified as follows:

1st. Requests for information covered by previous publications. — This is furnished where the time required for copying the answer is not too large. Where the portion desired cannot be copied, the enquirer is told in what volume and page it occurs and advised how to proceed to get access to a copy of the report.

2nd. Requests for identification of minerals and fossils. — This is done, where possible. As a rule, the minerals and fossils are simple and familiar forms, which can be answered at once. In occasional cases, a critical knowledge is required and time for investigation is necessary. Each assistant is expected to co-operate with the State Geologist in answering inquiries concerning his field.

3rd. Requests from private individuals for analyses of minerals and ores, and tests to establish their commercial value. — Such requests are frequent. They cannot be granted, however, except in rare instances. Such work should be sent to a commercial chemical laboratory. The position has been taken that the Geological Survey is in no sense a chemical laboratory and testing station, to which the people may turn for free analytical work. Whatever work of this sort is done, is done on the initiative of the Survey and not at the solicitation of an interested party.

The greatest misapprehension in the public mind regarding the Survey is on this point. Requests for State aid in determining the value of private mineral resources, ranging from an assay worth a dollar, up to drilling a test well costing several thousand dollars, represent extreme

cases. At present there is no warrant for the Survey making private tests, even where the applicant is entirely willing to pay for the service. In many cases individuals would prefer the report of a State chemist or State geologist to that of any private expert, at equal cost, because of the prestige which such a report would carry. But it is a matter of doubt whether it will ever be the function of the Survey to enter into commercial work of this character; it certainly will not be unless explicit legal provisions for it are made.

4th. Requests from a number of persons representing a diversity of interests, who jointly ask the Survey to examine into and publicly report upon some matter of local public concern.— Such cases are not common. It is not always easy to determine whether such propositions are really actuated by public interest or not. Each case must be judged on its merits. The Survey will often be prevented from taking up such investigations by the lack of available funds, while otherwise the work would be attempted.

The reputed discovery of gold is one of the most prolific sources of such calls for State examination. It usually seems wise and proper to spend a small sum in preventing an unfounded rumor from gaining acceptance in the public mind, before it leads to large losses, and unnecessary excitement. The duty of dispelling illusions of this sort cannot be considered an agreeable part of the work of the Survey, but it is nevertheless of very direct benefit to the people of the State.

BULLETIN No. 1.

**THE
OCCURRENCE AND EXPLOITATION
OF
PETROLEUM AND NATURAL GAS
IN OHIO,**

BY

JOHN ADAMS BOWNOCKER, D. SC.

PROF. EDWARD ORTON, JR., *State Geologist*:

MY DEAR SIR: — I transmit herewith a report on The Occurrence and Exploitation of Petroleum and Natural Gas in Ohio, the field work for which was done during the summers of 1900, 1901 and 1902. During the last summer Mr. M. W. Mumma assisted, his time having been given to the Trenton limestone fields. I place on record at this place my appreciation of his energy and efficiency. Many citizens of the state have rendered assistance, and an effort has been made to give them due credit at the proper place in this volume. The Ohio Oil Company generously supplied field maps of the Trenton limestone areas, and the Carter Oil Company, through H. M. Stanberry, rendered like service in the southeastern part of the state. Hon. Harry E. Smith of Marietta, who is well informed concerning the oil and gas territory of his part of the state, has been extremely obliging and encouraging.

In conclusion I desire to extend to you my sincere thanks for your hearty co-operation.

Respectfully submitted,

May 1, 1903.

J. A. BOWNOCKER.

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THE OIL AND GAS-PRODUCING ROCKS OF OHIO.

THE PRINCIPAL DIVISIONS OF THE GEOLOGICAL SCALE IN OHIO, AND
THE OIL- AND GAS-BEARING MEMBERS.

2 S. G.

THE ORDOVICIAN.

In Ohio the upper half only of this great division needs be considered. This has been divided by Orton as follows:

	Feet.
3. Cincinnati series	300—750
2. Utica shales	0—300
1. Trenton limestone (out-crop)	0—50

The Trenton Limestone.—Quite the reverse, however, with the first member, known as the "Trenton Limestone." Not only is this the most important source of oil in Ohio, but probably it is not excelled by any single formation in the world. It forms the floor, so to speak, of the entire state, being found wherever the drill penetrates to a sufficient depth. It outcrops only in one locality, viz., along the Ohio River, in the southwestern corner of the state; but farther south, in Kentucky, it is the surface rock over a large area, and is the basis of the famous soils of the blue grass region.

The composition of the Trenton has been made the subject of careful investigation by Orton, who found that the oil and gas bearing beds are magnesian. This is shown by the following analyses:

	CaCO ₃	MgCO ₃	Insol. Res.	Al ₂ O ₃ and Fe ₂ O ₃
Findlay gas rock.....	53.50	43.05	1.70	1.25
Bowling Green gas rock..	51.78	36.80	4.89	....
Lima oil rock.....	55.90	38.85	.75	2.94

It was further found that in some places, at least, the magnesian character of the rock changes rapidly from the surface of the formation down. Thus an analysis of the rock lying 100 feet below the top of the Trenton at Bowling Green showed over 88 per cent. of CaCO₃ and less than 7 per cent. of MgCO₃; while, as shown above, the upper portion of the same formation has less than 52 per cent. of CaCO₃ and more than 36 per cent. of MgCO₃. The magnesian character is important, since it renders the rock porous, thus making it a suitable reservoir for the oil and gas. Outside of the producing territory in Ohio, the Trenton loses its magnesian character, the CaCO₃ composing usually at least 75 per cent. of the formation.

The rock is often highly fossiliferous, and occasionally the pieces brought up by the sand pump are little more than a cemented mass of

shells, resembling in this respect the limestones of the Cincinnati series. Dr. Orton referred the formation, as shown in the Findlay well, to the Galena, Trenton proper, and Birdseye divisions.¹ The total thickness of the Trenton in northwestern Ohio is unknown, but it exceeds 780 feet. In the southwestern part of the state it is 650 feet, as shown in a well drilled on the McGhee farm in Liberty township, Adams county. This thickness is similar to that reported in Kentucky.

The relation stratigraphically of the Trenton to the next important producer, the Clinton, is shown in the following record of Well No. 1, drilled on the Haines farm, near Roseville, Sandusky County.

	Feet	
Drive pipe	30	
Niagara series,	{ Gray lime	140
	{ White lime	160
	{ Blue lime	20
	{ White slate, first break.....	2
	{ Brown lime, hard.....	21
	{ Light slate, second break...	20
Clinton limestone	100	
Medina shales (red).....	80	
Cincinnati series (white shales).....	427	
Utica shale (brown).....	252½	
Trenton limestone at.....	1,252½	

For comparison, a record is given of a well drilled on the Rohr farm, near Groveport, Franklin county, in the central part of the state:

	Feet
Drift	136
Ohio shales	167
Corniferous limestone, top at.....	303
Niagara limestone, bottom at.....	980
Clinton shales	110
Clinton sand, shells only at.....	1,110
Trenton limestone at	2,146
Bottom of well (in Trenton).....	2,675

THE SILURIAN.

The rocks of this age in Ohio are divided by Orton as follows:²

	Feet
4. Lower Helderberg limestone.....	50—600
3. Niagara limestone and shale.....	125—380
2. Clinton group	20—150
1. Medina shale	25—150

¹*Geol. Sur. of Ohio*, Vol. VI, p. 116.

²*Ibid*, Vol. VII, pp. 4, 5

The Clinton.—Of these divisions, the second and fourth only call for recognition in this chapter. Along its line of outcrop in southwestern Ohio, the Clinton consists essentially of a highly crystalline limestone, rich in fossils, especially crinoid stems. Commonly it has a light color, the tint of which varies from place to place. The rock takes a good polish, and is sometimes called marble. Occasionally the formation contains lean hematite, and one of the earliest blast furnaces in the state relied on this ore. In composition the rock is calcareous, and at one point becomes the purest rock of this type in the state.

Northward, under cover, the rock undergoes notable changes, the result being that it closely resembles the overlying Niagara. It is in the central portion of the state, however, that the greatest change is found. Instead of a well-marked limestone, there is found in its place shales of different colors and composition and a conspicuous sandstone; the latter the repository for the great reservoirs of gas in Fairfield, Hocking, Licking and Knox counties. In northern Vinton county a pool of oil also has lately been found, and one well has been secured in Perry county.

The relations of these beds to the overlying Niagara are shown in the following partial log of a well on the Bauer farm, near Sugar Grove. Samples of drillings below the Niagara were taken by the writer:

		Feet
Berea grit	{ top at	620
	{ bottom at	645
Corniferous, Helderberg, and Niagara limestones.	{ top at	1,430
	{ bottom at	2,132
Clinton {	Shales, light chocolate-colored.	{ top at 2,132
	Little lime	{ bottom at 2,168
	Shales, green and chocolate-colored,	{ top at 2,168
	the latter fossiliferous. Some lime.	{ bottom at 2,199
	Shales, green and chocolate-colored.	{ top at 2,199
	Much lime	{ bottom at 2,236
Clinton sand at		2,236

Generally when the gas sand has been penetrated to a depth of from 10 to 15 feet the drill is stopped, and consequently data farther down are less abundant. In western Ohio the basal portion of the Niagara is commonly occupied by shales,¹ but northward and eastward this member contracts. In central Ohio it consists of shales and thin beds of limestone, and the bottom of these is regarded as the line of junction of the Niagara and the Clinton.

¹*Geol. Survey of Ohio*, Vol. VII, pp. 11-13.

The following skeleton record of a well on the Spire farm, near Sugar Grove, shows the position of the Medina as well as the Clinton:

	Feet
Drift	11
Berea grit, bottom at.....	460
Corniferous, Helderberg, and Niagara limestones.....	top at 1,235 bottom at 1,921
Clinton sand	top at 2,025 bottom at 2,045
Medina (red shales) top at.....	2,055
Bottom of well at	2,075

This makes the red shales, lying from 10 to 30 feet below the Clinton sand, the top of the Medina.

The Lower Helderberg.—Rocks of this age produce gas and oil in one locality, viz., near Jefferson, Ashtabula county. The succession of strata there is shown by the following record of Webb Well No. 1. All measurements were made with a steel line.

	Thickness of formation. Feet.	Total depth. Feet.
Drift	33	33
Ohio shales	1,671	1,704
Corniferous and Lower Helderberg lime- stones	288	1,992
Gas sand at		1,992

The sand, which is from 30 to 40 feet in thickness, is interbedded in the Lower Helderberg limestone. Similar conditions are found in Lucas and Wood counties, in the former of which the sand has been quarried for the manufacture of glass.¹ In the gas field under consideration the sand is moderately coarse, has a light color, and is highly fossiliferous. The gas is found in the top of the formation, and just below lies a large and threatening reservoir of salt-water. A number of towns and villages are being supplied with fuel from this field. The oil wells are few in number and insignificant in production.

THE DEVONIAN.

The rocks of this age, found in Ohio, have been classified by Orton² as follows:

	Feet.
3. Ohio shales	250—3,000
2. Olentangy shale	25
1. Devonian limestone (Corniferous).....	75

¹*Geol. Survey of Ohio*, Vol. VII, p. 17.

²*Ibid.*, pp. 4 and 18-26.

None of these formations produce oil, and the Ohio shales alone yield gas. The available supply of this, however, is very small, and its use has been limited to domestic purposes. The principal counties have been those along the lake shore, in the northeastern corner of the state. These shales, which underlie the eastern half of the state, are wedge-shaped, with the apex reaching from the lake to the Ohio. The cities, Columbus, Delaware and Bucyrus, lie on or near this apex. Eastward the formation thickens rapidly, and near Wellsville, on the Ohio River, has been penetrated to a depth of 2,600 feet without reaching the base. This feature has led to much confusion on the part of the driller, who has expected to find the interval between the Berea grit and the Devonian limestone, the same in the eastern part of the state that he did in the central.

The gas secured in these shales is not from any one horizon, but varies stratigraphically from place to place. The wells are all small. Very commonly the shales make a show of gas, but usually the yield is so light as to be commercially valueless. The aggregate amount contained, however, must be very large, and if it could be collected would form one of the most valuable supplies of fuel in the state.¹

THE CARBONIFEROUS.

Classifying the formations of this great division, as has been customary, into the Lower Carboniferous, Coal-measures, and Permian, it is found that the oil and gas bearing rocks are restricted to the first two members. These will now be considered in order.

I. THE LOWER CARBONIFEROUS.

The Berea Grit.—This is the most extensive sandstone of the state. Its area above and below drainage is about 15,000 square miles, or more than one-third of the area of the state. Its value is commensurate with its extent. "Its economic value above ground is great, but it is greater below. In its outcrop it is a source of the finest building-stone and the best grindstone grit of the country, and when it dips beneath the surface it becomes the repository of invaluable supplies of petroleum, gas and salt water."²

The composition and structure are very constant. The color is gray below drainage, but has a tinge of yellow above. The sand is of moderate fineness, and composed almost wholly of silica. Occasionally it contains carbonate of lime, probably as a cement, but this never constitutes more than a very small fraction of the formation. That found

¹For a full discussion of this subject see *Geological Survey of Ohio*, Vol. VI, pp. 410-442.

²*Ibid.*, Vol. VII, p. 28.

below the surface, around the village Berea, in Cuyahoga county, is undistinguishable from that obtained at a depth of more than 2,000 feet in Washington county. Sometimes, though not usually, the formation divides, a bed of shale lying between two of sandstone; at other places the upper portion of the formation consists of sandstone and the lower of shales. In thickness the formation varies from 50 feet or more in the northern part of the state to a half dozen or less in the southeastern portion, and occasionally disappears entirely, its place being occupied by shales. The Berea grit is succeeded above by the Berea (Sunbury) and Cuyahoga shales, having usually an aggregate thickness of from 500 to 600 feet, and below by the Ohio shales, having a great and rapidly increasing thickness eastward. The most remarkable character of the formation, however, remains to be mentioned, viz., its persistence. From its outcrop it has been followed by the drill from county to county, and often from section to section, until the eastern and southeastern limit of the state is reached. It is as easily recognized below drainage as above, and this character makes it a stratigraphical landmark of great value to both driller and geologist. In many counties in the eastern part of the state, especially those fronting on the river, numerous efforts have been made to find a productive sand below the Berea, but in every case this effort has been unsuccessful. It may now be taken as having been demonstrated by the drill that when the Berea sand has been passed in this territory the last hope of oil or gas has gone.

While a trace of oil or gas has perhaps been found in every county where the formation exists, the production in commercial quantities is limited to Lorain, Medina, Trumbull, Columbiana, Stark, Jefferson Harrison, Belmont, Guernsey, Monroe, Noble, Vinton, Perry, Athens, Morgan and Washington counties.

The Logan Group.—The relative position of this group and the Berea is shown by the following skeleton record of a well on the Mead farm, in the Elk Run Pool, Washington county.

			Feet.
Pottsville conglomerate	{ Salt sand	{ top at	1,200
		{ bottom at	1,280
Maxville limestone	{ Maxton sand.....	{ top at	1,450
		{ bottom at	1,500
Mountain limestone ("Big lime")	{	{ top at	1,510
		{ bottom at	1,545
Logan group	{ Big Injun series....	{ top at	1,560
		{ bottom at	1,730
Berea grit	{	{ top at	2,124
		{ bottom at	2,138

This shows that the two formations are about 400 feet apart, and as has already been stated, the interval is occupied by the Berea and Cuyahoga shales.

The Logan group, as classified by Orton, consists of three members—a conglomerate, sandstone and shale—and has a maximum thickness of 350 feet.¹ Quite recently, however, Professor Prosser has considered the question, and he divides the group as follows:²

2. Logan formation = Logan sandstone and shales.
1. Black Hand Formation = Logan conglomerate.

The Big Injun series is limited above by the Lower Carboniferous or Maxville limestone, which in Monroe, the southeastern corner of Belmont and the eastern part of Washington counties is known as the Mountain limestone, or, popularly with the driller, as the "Big lime." Outside of the two counties just named, however, this limestone is not reported, and hence the upper limit of the Big Injun is not so well marked. In fact, over a large part of eastern Ohio, this formation and the Salt sand are confused by the driller, who applies the latter name to the Big Injun.

Above drainage the group is well marked. Hills capped with sandstone or conglomerate stand out in bold relief, so that the limits of the formation are discernible from a distance. The conglomerate is the most conspicuous member of the group. It is essentially a quartz rock, the largest pebbles of which do not commonly exceed one-half of an inch in diameter. It is the best known bridge stone in the state. The sandstone member has usually a yellow or brown color, but sometimes this becomes strikingly variegated. It is extensively used for building purposes. The members of this group are much less constant in their physical characters than the Berea grit, and hence their identification is correspondingly more difficult.

Under cover the Logan group undergoes important changes, and the several formations are given different names from those at the surface. Thus, instead of the Logan conglomerate, sandstone and shale, we have the Keener, Big Injun and Squaw sands.

The Mountain limestone has been shown by paleontological evidence to be the equivalent of the Maxville or Subcarboniferous limestone. The formation is known in West Virginia as the Greenbrier limestone. In Ohio it has a maximum thickness of 110 feet. It is a light-colored, hard, massive rock, free from oil and gas except along its margin, where the formation becomes broken and the layers of limestone are intercalated with sandstone. The formation is wedge-shaped, with the apex to the northwest. It is limited to the eastern half of Washington and Monroe

¹*Geol. Survey of Ohio*, Vol. VII, p. 32.

²*Journal of Geology*, Vol. IX, p. 215.

counties, and the southeastern corner of Belmont. To the west and north its place is occupied in part at least by shales and sandstones. The formation makes the summit of the Lower Carboniferous, and serves as a guide-post to the driller.

The Big Injun Series.—This consists of the following members:

Slate	0— 20 feet
Keener sand	0— 60
Slate	0— 25
Big Injun sand....	0—175
Slate	0— 10
Squaw sand	0— 30

From this it is seen that the group varies greatly. Sometimes it is little more than one great mass of sandstone, while at other times it is broken into a series of alternating beds of slate and sandstone. The Keener sand occasionally lies immediately below the Mountain limestone, but more often is separated from that rock by a few feet of shales. It varies considerably in texture, but is usually coarse and open, sometimes conglomeritic. The sand was named from the Keener farm, near Sistersville, West Virginia.¹ It is an important source of oil in Monroe and Washington counties. The sand is separated from the underlying Big Injun by a bed of slate. Sometimes the latter is wanting, and then the two sands run together and are conjointly called the Big Injun. The sand in question (Big Injun) is by far the thickest member of the series, but in other respects resembles the Keener. It is recognized in several counties in southeastern Ohio, but is a producer of oil or gas in commercial quantities in Monroe and Washington counties only. To the west and north the formation becomes too broken to be a repository for oil or gas. Below the Big Injun, and separated from it by a thin bed of shales, there is occasionally found another layer of sand known as the Squaw. It is decidedly patchy, and never extends over large areas in this state. The best records of it are reported from Monroe county, but it is of little importance even there.

II. THE COAL MEASURES.

These include not only the formations containing seams of coal, but also several hundred feet of rock lying between the Sharon or No. 1 coal and the Mountain limestone. This is part of the great Pottsville conglomerate. For convenience the rocks of the Coal-measures will be divided into first, the Pottsville Group; second, the Coal Measures proper.

Pottsville Group.—This group of sands lies in the lower part of the Pottsville conglomerate, that is, between the Sharon or No. 1 coal and

¹West Virginia Geol. Survey, Vol. I, p. 357.

the Mountain limestone. It may be well to state that in Southeastern Ohio the Pottsville formation loses its conglomeritic nature, and becomes sandy and shaly. There are two sands that should be noticed, viz., the Salt sand and the Maxton sand.

The relative positions of these are shown in the Mead farm record given on page 23.

The Maxton Sand.—This rests immediately on the mountain limestone, or is separated from it by a few feet of shales. The sand has been reported in the eastern part of Washington and the southern part of Monroe counties only. Its area is small and within this the sand is patchy. It is of little importance as a producer of oil or gas.

The Salt Sand.—This sand, as its name indicates, contains much salt water. It was the source of the brine of the salt works which formed so important an industry in southeastern Ohio one-half century ago. Testing for it was an important aid in proving the existence of oil in the rocks of the Coal-measures. It is very generally confused with the Big Injun sand in those counties where the Mountain limestone is not found. The Salt sand is not important as a producer of either oil or gas.

Coal-Measures Proper.—While a large number of strata belonging to the Coal-measures have been or are now sources of oil, comparatively few of these have been important in a commercial sense. Generally the sands are local, and cannot be traced over an area of more than a fraction of a mile. Such sands usually have names, but because of their small area and production they will not be further noticed in this article. The most important sands of the Coal-measures are the following:

5. Goose Run sand.
4. Mitchell sand.
3. First Cow Run sand.
2. Macksburg 500-foot sand.
1. Second Cow Run sand.

The relative positions of sands 1 and 3 are shown by the following data taken from Centennial Well No. 6 at Cow Run:

	Thickness. Feet.	Depth to top of formation in feet.
Pittsburg coal	1	11
First Cow Run sand.....	47	325
Second Cow Run sand.....	64	776

The stratigraphical relation of sands 2 and 3 is shown by the following record taken from Dunn Well No. 6, near Macksburg. The well head is six feet below the Meigs Creek coal.

	Thickness. Feet.	Depth to top of formation in feet.
Ames limestone	1	285
First Cow Run sand.....	5	385
Cambridge limestone	4	411
Dunkard sand (300-foot).....	95	530
Macksburg 500-foot sand.....	22	702

The Dunkard or 300-foot sand is quite generally regarded as the equivalent of the Mahoning. That this cannot be correct is shown by the following partial section of the Hocking Valley coal field.¹

	Thickness in feet.
Cambridge limestone	2-10
Mahoning sandstone, upper division.....	50
Brush Creek coal (No. 7a).....	2½
Brush Creek limestone.....	4
Mahoning sandstone, lower division.....	15-25
Upper Freeport coal.....	0-3
Upper Freeport { Clay.....	35
{ Shales....	
{ Limestone and sandstone.....	
Middle Kittaning coal (No. 6).....	5-13

This shows the Mahoning sandstone lying immediately below the Cambridge lime, but experience in the field demonstrates that the two are not ordinarily in contact. Measuring from the base of the lime rock to that of the Mahoning, an interval of 76 feet is found, while, according to the records in the Dunn well, the interval is 210 feet. A divergence of this sort cannot be explained by assuming that the section expands eastward, for a study of the relative positions of the Pittsburg coal, the Ames and Cambridge limestones farther west with the same formations near Macksburg, shows no material change, and it is certainly unreasonable to assume that the formations just below the Cambridge limestone expand at anything like the rate that would be necessary to make the interval which this nomenclature requires. Further, naming the sand in question the Mahoning makes impossible a rational classification of the lower formations. The position of the sand with reference to the Cambridge lime is that of the Upper Freeport.

The positions of sands 3 and 4 are shown by the record of Centennial Well No. 7, at Cow Run. The well head is at the horizon of the Meigs Creek coal.

	Thickness. Feet.	Depth to top of formation in feet.
Pittsburg coal (No. 8).....	1	116
Mitchell sand	25	205
Red shales ("Big Red").....	80	235
First Cow Run sand.....	32	423

¹*Geol. Sur. of Ohio*, Vol. V, p. 918.

The relative positions of sands 4 and 5 are shown by the following taken from Reed Well No. 4, near Marietta:

Goose Run sand.....	{ top at..... 300 bottom at... 331
Mitchell sand.....	{ top at..... 525 bottom at... 546

The Second Cow Run Sand.—This is one of the least important members of the group now under consideration. It has been a small producer at Cow Run in Washington county for more than thirty years, but rarely has been found beyond that locality. It is reported, however, quite frequently, for the driller gives this name to almost any sand lying from 100 to 500 feet below the first Cow Run sand. As may be seen from the records given the interval between the two is 400 feet. It lies 760 feet below the Pittsburg coal, and is the thickest member of the group, sometimes exceeding 60 feet. Occasionally the formation is divided by a few feet of slate, in which case the oil lies in the lower part. The sand possesses no qualities that serve to distinguish it from the higher members.

The sand belongs near the base of the Coal-measures. The partial record of the Rice well, given below, shows it to be the first sand above the Salt sand, the two being separated by 79 feet of shales, the latter probably the equivalent of the shales of the Logan group. This, with the thickness of the formation, and the fact that it is sometimes divided by a few feet of shales, makes quite certain its identification as the Massillon sandstone.

The Macksburg 500-Foot Sand.—This is important at Macksburg and vicinity only. It lies 670 feet below the Meigs Creek coal and about 580 feet below the Pittsburg, as is shown in the following partial log of George Rice Well No. 18, at Macksburg:¹

	Thickness. Feet.	Depth to top of formation in feet.
Meigs Creek coal.....	5	10
First Cow Run sand.....	35	343
Dunkard sand (300-foot).....	78	554
500-foot sand	17	685
Sand, pebbly (800-foot).....	51	775
Slate	79	826
Salt sand.....	190	905

This sand commonly ranges from 10 to 30 feet in thickness. It is usually quite coarse, but does not become a conglomerate. Like the First Cow Run sand, it does not form a continuous stratum, but is decidedly patchy. Stratigraphically considered, the formation belongs near the top

¹*West Virginia Geol. Sur.* Vol. I, p. 298.

of the Conglomerate Coal-measures, and its position with reference to the Cambridge lime and Dunkard sand strongly indicates that it is the Tionesta sandstone.

The Second Cow Run and the Macksburg 500-foot sand have been regarded by many as equivalent. As has already been suggested by Professor White, however, this cannot be the case.¹ Examination of the record of the Rice well shows that the interval between the First Cow Run and 500-foot sands is only 307 feet, while, as already stated, the interval should be 400 feet. Measuring from the Meigs Creek coal, equally conclusive figures are secured. Thus the Second Cow Run sand lies 840 feet below the Meigs Creek coal, while the interval between this seam and the 500-foot sand is only 670 feet. The sand at Macksburg known as the 800-foot is probably the equivalent of the Second Cow Run.

The First Cow Run Sand.—This is the most important and best-known sand of the group. As is shown in the record of the Dunn well, its position is 100 feet below the Ames limestone. In western Morgan county, near the outcrop of the sand, the interval ranges from 70 feet to 100. The Ames limestone there lies 170 feet below the Pittsburg coal. The identification of the sand is made more certain by the fact that the Cambridge limestone lies immediately below or is separated from the sand by a thin bed of shales. Unfortunately these limestones are not recognized in Monroe and the eastern part of Washington counties, hence the sand in question often cannot be identified there with certainty. In such localities any shallow sand, especially if it makes a show of oil or gas, is known as the Cow Run. The relation of the sand to the two limestones places it about 100 feet above the base of the Conemaugh formation.

If the Berea grit be taken as the type of a persistent stratum of sandstone, the First Cow Run sand may properly be selected as the representative of the opposite type. It is the most patchy of the oil or gas rocks of Ohio. The maximum thickness of the formation may be taken at 50 feet, but even a short distance from this the stratum may become very thin or actually disappear entirely. The texture varies much, and where productive is sometimes conglomeritic. Pebbles three-fourths of an inch in diameter have been found, and those one-fourth of an inch are common. The pebbles consist of quartz, but small grains of other minerals are found. From this type the formation changes to a hard compact sandstone.

The sand is an important source of oil in Morgan and Washington counties. It seems to have been first struck at Macksburg in 1860, where it is known as the 140-foot sand; this being the depth at which the sand was found in the valley at that place. In 1861 the sand was found at Cow Run and has there been a producer ever since. It is seen that the latter name has not the claim of priority, but it is so much more widely used that it is here retained.

¹*West Virginia Geol. Sur.* Vol. I, p. 299.

The Mitchell Sand.—This is the source of a small oil field a few miles east of Marietta. The sand is comparable in thickness with the First Cow Run, but in texture is less conglomeritic. As has been shown, it lies about 90 feet below the Pittsburg coal, or 200 feet above the First Cow Run sand. Its place is near the summit of the Conemaugh formation. Wells in this sand commonly begin with a relatively large production, but decrease very rapidly.

The Goose Run Sand.—The formation known by this name has supplied a score or more small wells near Marietta. The sand is patchy, and the life of the wells very short. In fact, the rock is of little value, and is recognized here simply to make the record complete stratigraphically. Lying nearly 200 feet above the Mitchell, the sand belongs 100 feet above the Pittsburg coal, or, in other words, near the middle of the Monogahela formation.

The following table shows the great divisions of the Coal-measures proper in Ohio, and also the approximate positions, at least, in these of the several sands just discussed:

Dunkard Formation, or Upper Barren Coal-measures, 500 feet.	{	No oil or gas rocks.
Monogahela Formation, or Upper Productive Coal-measures, 200 feet.	{	Goose Run sand. 100 feet (interval). Pittsburg or No. 8 coal.
Conemaugh formation, or Lower Barren Coal-measures, 500 feet.	{	90 feet (interval). Mitchell sand. 200 feet (interval). First Cow Run sand. Cambridge limestone. Mahoning sandstone.
Allegheny Formation, or Lower Productive Coal-measures, 250 feet.	{	Upper Freeport or No. 7 coal. Dunkard or 300-foot sand=? Freeport sandstone. 50 feet (interval).
Conglomerate Coal-measures, 250 feet.	{	Macksburg 500-foot sand=? Tionesta sandstone. 70 feet (interval). Second Cow Run sand=? Mas- sillon sandstone. Sharon or No. 1 coal.

CHAPTER II.

THE TRENTON LIMESTONE AS A SOURCE OF OIL AND GAS.

This article is largely a review. The exhaustive reports of the late Dr. Edward Orton, published in 1888 and 1890, have greatly limited the field of the present writer. The early historical data contained in this chapter are based almost wholly on the reports of the geologist just named, and the same is true of the fundamental principles of the geology of the field. The present writer has merely taken up the work where Dr. Orton laid it down, attempting to show the progress made and the present state of the industry.

THE DISCOVERY OF OIL AND GAS IN THE TRENTON.

Knowledge of the existence of oil and gas in the rocks of Ohio dates back almost to the period of the state's admission into the union. This resulted quite largely from the search of the pioneers for that necessary article, common salt. Thus a well drilled in 1814, near the village South Olive, Noble county, with this in view found such a pressure of gas that it threw the water and some oil to a height of from 30-40 feet, and these eruptions were continued as late at least as 1838.¹ About the same time both oil and gas were discovered in Washington county to the south. The petroleum was called Seneca oil, and was used in a small way for medicinal, illuminating, and lubricating purposes. Similar results were secured at many points in the southeastern part of the state, but the oil and gas were regarded as a nuisance. The former ruined the brine for the manufacture of salt, and the gas was regarded too dangerous. Deep wells, however, did not furnish the only evidence of mineral wealth stored in the rocks below. Sometimes ordinary water wells would liberate small quantities of oil or gas, and occasionally these products were found in still shallower excavations. At a few points oil was found as a very thin film on the surface of streams, and occasionally gas escaped with spring waters, the combination having been known as gaseous springs. It is interesting to note that evidence of this kind led later to tests at several points with the result that valuable pools of oil and reservoirs of gas were discovered in Washington, Morgan and Knox counties, and finally the great Trenton limestone field itself.

¹*Geol. Sur. of Ohio*, First Ann. Rept. 1838, p. 62.

The Discovery at Findlay.—These early discoveries of gas played a small part in the fuel supply of the state; in fact they were little more than scientific curiosities. The same is practically true of oil; for while the total value of the production from 1860 to the close of the year 1884 was \$579,223,¹ it is significant in comparison with the vast treasure that has been taken from our rocks since that time. Had the state's production of oil and gas terminated with the year 1884, these products would never have been ranked among the important sources of wealth in Ohio, nor would the state have been mentioned, except in a passing way, in works devoted to these fuels. The importance of the discovery at Findlay was estimated by Dr. Orton in 1888 as follows:—"No geological discovery ever made in the country, unless the original discovery of petroleum in western Pennsylvania shall be excepted, has exerted so widespread and powerful an influence on half of the United States, or at least on the northern Mississippi valley, as the discovery of Findlay gas."² Viewed from the standpoint of the production of wealth, however, the discovery of gas was of small importance in comparison with that of oil; for the Trenton limestone must now be rated as one of the first, if not the first, formations in the world as a source of petroleum.

Indications of natural gas had long been noted at Findlay and vicinity; along the banks of the Blanchard river the gas found its way to the surface, and it was also found in small quantities in digging water wells and sewers.³ The earliest specific mention of the fuel was made in 1836 when it was struck at a depth of perhaps ten feet. The gas was ignited, and the flame is reported to have been maintained for a period of three months. In 1838 a stronger flow was found, this time in the town of Findlay; and the fuel, collected in rude fashion, was used in a residence. It is interesting to report that gas was still being used in this manner in the residence referred to when the great discovery was made in 1884. As early as 1864 Dr. Charles Oesterlin, a citizen of Findlay, urged the construction of reservoirs to store the natural gas, preparatory to using it for domestic purposes.⁴ However, his ideas were in advance of his time and nothing came from them. Twenty years later the neighboring state, Pennsylvania, was enjoying benefits resulting from the discovery of vast volumes of natural gas. The people of Ohio were quick to see the possibilities of the new fuel and began testing the underlying rocks for it. This work aroused Dr. Oesterlin's interest which had been dormant for twenty years, and in the spring of 1884 he succeeded in organizing a company to test the rocks at Findlay.⁵ An experienced driller was secured from Bradford, Pennsylvania, and on October 20 work was begun. Small volumes of gas were found at several horizons, the supply being adequate for drilling. At 1092

¹*Mineral Resources of the U. S.*, 1900, p. 542.

²*Geol. Sur. of Ohio*, Vol. VI, p. 117.

³*Ibid.*, p. 109.

⁴*Ibid.*, p. 110.

⁵*Ibid.*, p. 111.

feet a much larger flow was found, sufficient to produce a flame from 20 to 30 feet in height. This attracted much attention in northwestern Ohio and produced great excitement at Findlay. With the hope of finding a larger body of gas the drill was kept at work until the rock in which the fuel was found had been penetrated to a depth of 556 feet, but without success. While this well was small it demonstrated the presence of gas in the underlying rocks, and this was sufficient to make further exploration certain. The Findlay Gas-Light Company quickly saw the significance of the new discovery, and began drilling a well in December, 1884. The results were very similar to those secured from the first well, but the company turned the gas into its lines and Findlay for the first time was using natural gas.

Well No. 3, completed in June, 1885, was likewise small, but No. 4 had an initial flow of 1,250,000 cubic feet in 24 hours,¹ and was the first that could be rated successful. More, however, remains to be said of this well; oil appeared "at the same time and at the same horizon, at which the gas was found."² Later the quantity of oil increased, becoming about five barrels per day late in 1885. When the Karg well was completed the gas in the well under consideration decreased, but at the same time the oil increased from 5 to 15-20 barrels per day. Facts pertaining to this well have been given with some detail since it seems to have been the first in the vicinity of Findlay from which oil was secured in the Trenton limestone. Well No. 5 also showed some oil; but this was regarded as a nuisance, and an effort was made to exclude it from the gas rock by inserting a plug, the oil apparently coming from a lower horizon than the gas. The effort was only partially successful. Well No. 7, drilled in November, 1885, had an initial production of 3,335,000 cubic feet per day, making it the largest up to that time in the field. The next well was a failure as a producer of gas, but after having been shot with 100 quarts of nitro-glycerine it began flowing oil at the rate of 300 barrels per day. The volume decreased rapidly, but the well was by far the largest producer of oil yet drilled in the new field.³ Wells from Nos. 9 to 12 inclusive displayed no new features, or striking characteristics, and hence will not be further mentioned in this report.

It remained for the next well, "unlucky thirteen," to revolutionize the history of the field, and to make Findlay for a time the most conspicuous town in Ohio. This was the Karg well. It was located near the railroad station in Findlay, and was drilled by the Findlay Gas-Light Company. Work was begun in December, 1885, and the well was completed 24 days later. The Trenton limestone was struck at 1,118 feet, but the flow of gas was small and the drill was kept at work, as was customary under such conditions, with the hope of finding a larger supply. At 1132 and 1138 the flow increased, and at 1144 it became so great that the tools

¹*Geol. Sur. of Ohio*, Vol. VI, p. 122.

²*Ibid*, p. 123.

³*Ibid*, p. 126.

were powerless to advance. The escaping gas seemed to make the earth tremble, and the roar could be heard several miles. When lighted the flame could be seen 40 miles away. The flow of gas was measured by Professor Robinson and found to be 12,000,000 cubic feet in 24 hours. It was the largest well that had been drilled up to that time in Ohio, and gave new character to the Findlay field.¹ The discovery of oil and gas in the Trenton limestone has now been reviewed. It will be in order to consider each separately from this time, and since gas was first discovered, and also first to make its presence felt, it will be given the place of priority in this volume.

A RESUME OF THE HISTORY OF NATURAL GAS IN NORTH-WESTERN OHIO.

Drilling in Findlay continued and by the spring of 1888 the eighteenth well had been completed. None of the later ones, however, were large, the best not exceeding 2,500,000 cubic feet per day. From Findlay as a center drilling radiated in all directions, and it was not long until the limits of the gas producing belt had been determined. This extended north and south a distance of 25 miles and in a general way was limited by Findlay on the south and Bowling Green on the north. The richest territory included seven townships in Hancock county and six in Wood. It follows from what has been said that the producing territory did not form a line or ridge, but a broad belt in some places 15 miles or more in width. The wells secured outside of the corporation of Findlay were similar to those secured within; some were small, others large, a few gigantic. The Tippecanoe well was a good illustration of the latter type; it was located two miles north of the court house, and when the Trenton rock had been penetrated to a depth of 70 feet a good flow of gas was found. With the hope of increasing this the well was torpedoed, the result being the strongest flow of gas that had yet been secured in Ohio. Measurements made on the first three days of the well's existence showed productions of 32,000,000, 24,000,000 and 19,000,000 cubic feet respectively.² It is interesting to report that the owners of this well offered to sell it to the Findlay municipal natural gas plant, but the trustees of this declined to purchase, and began drilling a well only 60 feet from the Tippecanoe. The result was a total failure, and shows the extreme capriciousness of the industry, even when in territory that is regarded most promising. The Van Buren was another famous well. It was located on section 12 of Allen township, and was completed in October, 1886, but was not tubed for a month later, when it flowed nearly 13,000,000 cubic feet through a four-inch pipe in 24 hours. Two additional giants were drilled in this township; one known as the Hutson, on section 17, had an initial production

¹*Geol. Sur. of Ohio*, Vol. VI, pp. 129-130.

²*Ibid*, First Ann. Rept., 1890, p. 117.

at the rate of 32,000,000 cubic feet per day; and the other, named the Mellott, on section 30, yielded at the rate of 27,000,000 cubic feet in the same time.¹

The territory in Wood county joined that in Hancock, thus forming one field. The general character of the wells in Wood county was similar to that in Hancock county, but no such giants were reported. Bloom township contained the best territory, more than 40 wells having been drilled in it. The largest of these, the Simons, had an initial production of 12,000,000 cubic feet per day.²

As soon as gas was discovered at Findlay the owners of the well began preparations to supply the town. A few weeks later the Gas-Light & Coke Company completed a well, the second one drilled in the field, and turned the fuel into its lines. This precipitated a fight between the two organizations, the first effect of which was the laying a second set of pipes through the city, and later the absorption of the first-named company by the second one. The rates established were reasonable enough, but to the citizens it appeared that they had fallen into the clutches of a monopoly, and a demand was made that the city should own and operate its own wells. Accordingly the legislature passed an act granting the citizens a right to vote on a proposition to bond the municipality for \$60,000, the money to be used in drilling wells, laying pipes, etc. It is scarcely necessary to state that the proposition carried by a large majority. A third set of pipes were laid through the town and drilling of wells begun. The first one was completed in November, 1886; others followed in quick succession, so that the municipality soon had an adequate supply of gas.³ The gas trustees met the popular demand by cutting the existing rates in two, but the Gas-Light & Coke Company, not to be outdone, responded by dividing in a similar manner the rates of the municipal plant. The trustees of the latter at once met the rates of the old one, but the latter organization preferred that the "merry war" go on, and each company made one further reduction. By that time the cost of a fire per month had been reduced from one dollar to fifteen cents. The Gas-Light & Coke Company was preparing to reduce its rate from fifteen cents to five, when it was purchased by the trustees of the municipal plant and thus the contest was brought to a close. This done prices again advanced; on November 1, 1888, they became 50 cents for each stove if paid before the tenth of the month; on October 1, 1889, rates were practically doubled, and later they were still further increased. At present (1902) the rates are 30 cents per thousand cubic feet, with a discount of 5 cents if the bills are paid before the tenth of the month.

Almost as soon as gas was discovered it began to be used in such factories as then existed in Findlay. As the wells increased in number

¹*Geol. Sur. of Ohio, First Ann. Rept., 1890, p. 125-6.*

²*Ibid.*, p. 135.

³*Ibid.*, Vol. VI, p. 140-1.

and strength, outside plants were attracted to the place, and new corporations were established. The great attraction, of course, was free fuel, guaranteed in some cases for five years. This was sometimes supplemented by gifts of land on which to locate factories, and sometimes still further inducements were made. The result was a steady growth of the town during two years and then a shorter period of wild speculation. The city limits, which at the time of the discovery comprised four square miles, were extended until they included an entire township. Land sold at exorbitant prices, and the population of Findlay increased from 4,500 in 1884 to 25,000 in 1889. The fall of that year saw the crest of the speculative wave pass and then the reaction began.¹

The uses made of the new fuel were many. They included glass houses, iron industries of various kinds, lime kilns, and brick yards. Those interested did their best to convince the people that the supply was unlimited, or that it was being produced in the interior of the earth as fast as taken out. With such seductive theories, and the fact that gas was furnished free or nearly so, it is no wonder that vast quantities were wasted. The city itself led the extravagance, illuminating its streets by torches burning by day as well as by night, and wasting in this manner alone at least 15,000,000 cubic feet per month during part of the year 1887. The great wells themselves were frequently ignited to interest people who had visited the city through curiosity, or to impress those with capital to invest. Factories used the fuel in a reckless manner, and private residences were not behind in this respect. To many it seemed easier to raise a window or open a door than to turn down the gas.

The result is well known. The time came quickly and suddenly when the citizens of Findlay were brought face to face with an inadequate supply of gas. This first became manifest early in the winter of 1888, when many of the plants were compelled to shut down during a part of the day owing to a shortage in the fuel supply. During the coldest weather one of the public schools was dismissed and at such times many complaints were received from residences. One of the troubles was the presence of salt-water in the pipes, the effect of which was to shut off the gas. The water was soon traced to the Karg well, and those who had given any consideration to the subject saw at once that the great well was doomed. It became evident that if Findlay's supply of gas was to be maintained new territory must be secured, and early in 1889 the corporation leased nearly 8,000 acres in the northern part of the county at an annual rental exceeding \$50,000. Later in that year good wells were secured on this territory so that Findlay again had an ample supply.²

Such in brief was the early history of natural gas at Findlay. The following letter gives the financial history of the municipal plant. It will

¹*Geol. Sur. of Ohio*, Vol. VI, p. 141-150.

²*Ibid*, First Ann. Rept. 1890, p. 113-6.

be seen from this that the plant was successful, even though at times the fuel was wasted or sold at absurdly low figures. The letter is from the Prosecuting Attorney of the county:

FINDLAY, OHIO, January 16, 1903.

MY DEAR SIR:

In reply to your letter of recent date, asking for information regarding Findlay's gas plant, I herewith submit the following, the amounts and dates having been given me by Mr. Ray, the City Clerk:

The first bonds issued for the construction and maintenance of the gas plant at Findlay amounted to forty thousand dollars and were sold September 1, 1886. Other issues followed as money was needed for the construction of the plant, being ten thousand dollars October 5, 1887; eight thousand dollars issued February 11, 1888; forty thousand dollars September 4, 1888; twenty thousand dollars September 24, 1888; seventy-five thousand dollars June 1, 1889, and fifty thousand dollars October 1, 1889, the entire issue of bonds being two hundred and forty-three thousand dollars.

These bonds were redeemed upon the following dates as they became due. Of the first issue twenty thousand dollars was paid in 1896; ten thousand dollars in 1901; ten thousand dollars being unpaid, not being due until 1906. Ten thousand dollars sold October 5, 1887, was paid in full in 1897. The issue of eight thousand dollars was taken up in 1901. Of the forty thousand dollars sold September 4, 1888, thirty thousand dollars was paid in 1902, the remaining ten thousand dollars not being due until 1903. The twenty thousand dollars sold September 4, 1888, was paid in full in 1898. Of the seventy-five thousand dollars issued June 1, 1889, ten thousand dollars was paid in 1894; ten thousand dollars in 1895, ten thousand dollars in 1898 and ten thousand dollars in 1899, thirty-five thousand dollars still remaining unpaid and not yet due. The issue of fifty thousand dollars on October 1, 1889, was paid in full in 1899.

That this plant was a money-maker and a good investment for the city of Findlay is shown by the fact that, in addition to maintaining itself and redeeming its bonds, the Gas Trustees had at the time the plant was sold, an excess of seventy-five thousand dollars, which was used for the purpose of purchasing city of Findlay refunding bonds or paying special improvements and for general running expenses of the city of Findlay.

In 1896 it was decided by the Gas Trustees that the gas supply was insufficient to supply all the glass factories and other industrial plants, and thereupon the gas supply was cut off from these institutions. The meter system was adopted and the gas plant was practically devoted to supplying private citizens, who were charged twenty cents per thousand feet, which departure brought about general dissatisfaction for a time and a more economic use of the gas.

This step induced the managers of the numerous factories who had located here on account of cheap fuel to move on to new gas fields, or to some location where they could readily get a coal supply, and out of some dozen glass factories, we have but one left with us at this time, which is a large institution and has doubled its capacity since 1896. While the factory uses coal for its principal fuel, yet at certain seasons of the year when the private consumers use less gas, there is an ample supply for this purpose. While one or two of these old glass factories still stand sentinel at the outskirts of our city, most of them burned at the time of the exodus.

On February 20, 1899, this gas plant was sold by the City Council of Findlay for the sum of one hundred and fifty thousand dollars cash. The only reason

for this sale, as near as we can find out, was, "too much politics," for the major portion of the citizens were adverse to the sale and an action was brought to enjoin the consummation of it. The question of the Council's right to sell the plant was carried to the Supreme Court of Ohio, where it was decided in favor of the Council.

The receipts from the sale of this plant were used for the purchase of city of Findlay bonds and the redemption of the existing gas debt. We have now in the gas sinking fund seventy-five thousand dollars in the city of Findlay bonds, drawing interest at from 4 to 6 per cent. The company purchasing this plant immediately advanced the price of gas from twenty to twenty-five cents per thousand feet, and seemingly are not giving any better service than did the city under the trustees' management.

Altogether, the gas plant at Findlay was a very successful venture and a most fortunate investment for the citizens, as it not only maintained and paid for itself, but also helped out on other investments and improvements and left a tidy sum in the treasury besides.

Hoping that this information will be of benefit to you, I am,

Yours very truly,

WILLIAM L. DAVID.

Professor John A. Bownocker.
Columbus, Ohio.

The early history of natural gas at Findlay was in all essential respects repeated at Bowling Green and North Baltimore.

Bowling Green lies 24 miles due north of Findlay, and after gas in large volume had been discovered in the latter place it was most natural that the citizens of Bowling Green should test the underlying rocks. In January, 1885, the Bowling Green Natural Gas Company was organized, and on February 4 following work on the first well was begun.¹ The summit of the Trenton yielded very little gas, and accordingly the drill was kept at work until the rock had been penetrated to a depth of 200 feet. This, however, did not improve matters; then the well was torpedoed with 300 pounds of rack-rock, and a fine flow of gas was secured. Arrangements were at once begun to pipe the town in order that the new fuel might be put into use. Before the year closed the company had drilled all told six wells; but three only of these could be rated as producers, the last one completed yielding more gas than all others combined. Other wells were drilled with fair success, but the results all told did not meet the ambitious ideas of many citizens of the town, and accordingly the legislature was asked and granted the municipality the power to issue bonds to the amount of \$25,000 to construct a municipal plant to furnish free gas to manufacturers. Drilling was at once begun and soon there was a supply adequate for all demands. The earlier wells were drilled in the main in Portage township, but later the municipality leased 500 acres in Bloom township, the richest of the Wood county territory. With a large amount of free gas offered the town began to reap the desired reward, for with such an inducement factories were easily secured. The establishments

¹*Geol. Sur. of Ohio*, Vol. VI, p. 156-162.

were given largely to the glass industry, and at one time over 3,000,000 cubic feet per day were used.¹

The result of this heavy call was the quick exhaustion of the territory. In the winter of 1888-9 the supply was far from meeting the demands, and the winter following the conditions were far worse. In fact, it may be stated that the decrease in the production was as rapid as its increase had been. The story is well told by the following rock pressures:²

Year.	Rock pressure in lbs. per sq. inch.
1887	450
1888	375-390
1889	290
1890	100

The decrease in production was in a general way proportional to that in rock pressure, and the year 1890 saw the beginning of the end.

The first well at North Baltimore was drilled in the summer of 1886, but it produced oil rather than gas. The second well was located about one mile south of the first one, but it was still less successful. The Peters well was the first successful producer of gas secured in this vicinity. It was located about three-quarters of a mile east of the village, and had an initial flow of at least 3,000,000 cubic feet per day.³ By 1889-90 the corporation owned three gas wells, all in the southeast quarter of Portage township. From this territory, three lines, a two-inch, three-inch and four-inch respectively were laid to the village. Funds to the amount of \$8,000 to accomplish this were obtained by bonding the town. Three factories, all glass industries, were early secured; the inducement being gas for a period of ten years at a charge of five dollars each per year. Besides this the three factories received in the aggregate \$24,500 in the form of donations from the town, the money having been secured from the sale of lots. A pressed brick factory also was supplied from this territory. All these establishments used the fuel in the most reckless manner; while the municipality itself and the residents of the place pursued the same wasteful policy.⁴ The result was as might be guessed; complaints were soon heard of insufficient gas, and this was the beginning of the end of gas for factories. Later the fuel was restricted to domestic purposes, but this wise move was not made until the gas-rock had been almost emptied.

Bowling Green and North Baltimore were not the only places in northern Ohio that were excited by the discovery of Findlay gas. In fact, every town in that part of the state felt the effect to a greater or lesser

¹*Geol. Sur. of Ohio, First Ann. Rept., 1890, p. 152-4.*

²*Ibid., p. 155.*

³*Ibid., Vol. VI, p. 227-9.*

⁴*Ibid., First Ann. Rept., 1890, p. 140-1.*

extent, and companies were quickly formed to test the underlying rocks with the hope of finding the fuel that produced such remarkable events. The results were in most cases disappointing, but the courses taken by the municipalities form an interesting chapter in our state's history. An outline only of this can be given here. A deep well was drilled at Toledo in 1885, and a number of others were put down shortly afterwards in different parts of the county. The most that can be said for these is that they made a showing of gas, but in 1887 the new fuel was piped to the city from Wood county by two companies; the Northwestern Ohio Natural Gas Company and the Toledo Natural Gas Company. The city council fixed the maximum rates that the companies could charge, and it was expected that competition would work to the city's interest, but the two companies did not engage in a contest similar to that which took place at Findlay. In fact, after a short time, they pooled their interests.¹ While the rates charged were not unreasonable no special inducements, such as free gas, were made to factories. In other words, these companies looked after their own interests rather than those of local real estate men. The result was that Toledo did not experience the boom that the smaller cities to the south enjoyed, and in 1888 a petition was presented to the legislature praying for the power on the part of Toledo to construct and operate a natural gas plant of its own. The bill did not pass at this session, however, but a year later received a large majority in each house. The act was ratified by a vote of the citizens in April, 1889, and the city council speedily authorized the sale of \$75,000 worth of bonds. The gas trustees at once began leasing territory in Wood and Hancock counties, paying a large annual rental thereon. On this wells were drilled. In addition the trustees contracted with the Stuartsville Land Association to furnish them with 50,000,000 cubic feet of gas per day, the trustees to purchase the wells producing this gas at \$1,000 for every million cubic feet of gas which they produced when purchased. Each well was to have on the average ten acres of land to draw on. Contracts of a similar nature were made with other parties.

When the bonds referred to above were advertised for sale, the Northwestern Ohio Natural Gas Company, a branch of the Standard Oil Company, entered the United States court, asking for an injunction against the sale of bonds, but the municipality won an easy victory. Late in the same year (1889) the company again brought suit, but the gas trustees were again victorious. The money derived from the first sale of bonds was speedily exhausted, and the trustees then offered for sale the remainder provided for by the special act of the legislature, amounting to \$675,000. One hundred thousand dollars' worth were taken by citizens of Toledo, but the remaining ones found no buyers. This was regarded as a result of the attack made by the Standard Oil Company, which seems

¹*Geol. Sur. of Ohio, First Ann. Rept., 1890, p. 146-151.*

to have prejudiced the bonds in the eyes of the capitalists that were expected to buy them.

The following interesting account of this plant was furnished by Mr. Robert Campbell. It is published in full, even though it repeats part of what has already been said:

"After gas had been discovered in Hancock and Wood counties, Ohio, investors from nearby towns and cities, including Toledo, became interested in territory of greater or less value. During 1887 and 1888 the towns of Findlay, Fostoria and Bowling Green were enjoying booms due to the fact that free gas for fuel was offered at these places as a bonus to manufacturers; but at Toledo no such offer could be made because the gas was furnished by a private corporation, The Northwestern Ohio Natural Gas Company. Even though the Northwestern offered to enter into a contract to furnish natural gas for five years at the very low rate of 12 cents per thousand cubic feet, still some of the Toledo investors in gas territory and their associates, the men who wished to reap a harvest of money by a boom advance in the values of real estate in and about Toledo, began in 1888 to agitate the municipal ownership of a natural gas plant.

"So successful was this agitation that in January, 1889, in reply to a petition from citizens of Toledo, the General Assembly of Ohio passed an act, subject to the decision of the electors of Toledo as expressed at the polls in April, providing that the Governor should appoint a board of trustees to conduct the work of securing and maintaining a natural gas plant as soon as the necessary funds were obtained by the sale of city bonds issued expressly for that purpose. During the months previous to the day for voting either for or against the act the strife between the parties favoring or disapproving the project became heated, and every inducement was offered to secure the vote of even the least interested electors. 'Free gas' was the hosanna cried to the poor, while to others assurance was given by these promoters that the gas plant would pay for itself in five years, clear away the municipal debt in another five, and pay the expense of city government and improvements thereafter. As was to be expected, the poor and non-taxpaying residents, who had everything to gain and nothing to lose, rushed to the polls and overwhelmed the vote of the tax payers, who were almost without exception opposed to the project.

"In accordance with the provisions of the act it now became the duty of the Governor to appoint a board of trustees, which was duly organized and began at once to negotiate for gas wells and territory. Naturally enough the territory most easily secured was the less valuable of the property of the investors who were promoting the scheme, for these men had no scruples about selling to the city their 'high pressure' wells as 2,000,000 cubic feet producers, whereas in reality the well was only a 50,000 cubic feet producer with almost no pressure at all.

"Later in the summer of 1889 an issue of bonds for \$500,000 was advertised. This announcement called forth into open battle a determined antagonist, the Standard Oil Company. By its agents injunction suits, based upon the alleged unconstitutionality of the act passed by the General Assembly, were filed both in the state and federal courts. The city won the case in both courts; still the Standard Oil Company caused circulars to be sent to dealers and investors in municipal bonds both in the United States and Europe, warning them against the purchase of the bonds as being illegal and void and issued under an act that was unconstitutional, giving notice that suits had been commenced in the courts. Furthermore, the movements of the trustees, or anyone authorized to sell the bonds, were so closely watched by spies, that whenever a trip was made to an eastern or western city by any of these men it was soon discovered that the enemy had preceded in order to close the ears of purchasers and their pocket-books as well. In the field the opposition of the Standard Oil Company was still more troublesome, for the agents of that corporation left no territory unvisited, and in certain localities favoring the Toledo enterprise even represented themselves as members of the board of trustees or as the president himself. Because of the unlimited capital of their corporation the agents advanced the price of rentals on undeveloped territory as much as 1000 per cent.; and land formerly worth 25 cents an acre per annum for gas rental could not be secured for less than \$10 or even \$20 an acre by the Toledo trustees. Altogether the loss to the city, due largely to the opposition of the Standard Oil Company in the matter of bonds and of purchasing territory, has been estimated at more than a million dollars.

"Notwithstanding all their troubles the trustees were finally able to secure natural gas, to construct a main line from the field, and to plant distributing pipes throughout the city. The supply of gas, however, soon became a vexatious problem, for at no time in winter was there enough gas to accommodate all consumers. The manufacturing plants were the first to have their connections removed, but even then the patrons at a short distance from the main line suffered during the severe weather, while those on the outskirts had no gas at all. To relieve this condition the General Assembly was petitioned in 1892 to pass the necessary legislation to allow the city to issue bonds to the amount of \$100,000 to meet the cost of bettering the gas plant and to secure a pumping station for the (Stuartsville) field. As soon as this work was completed and other pumps were introduced into the line the trustees were able to give fair satisfaction to the consumer until 1896.

"To provide for the great expense of securing natural gas and of constructing the gas plant, the city had sold from time to time the various issues of bonds here tabulated:

Amount.	Date issued.	Due.	Rate.	Interest.
\$ 75,000.00....	May 10, 1889	May 10, 1919..	4½ %..	\$ 3,375.00
100,000.00....	Oct. 1, 1889	Oct. 1, 1899..	4½ ..	4,500.00
100,000.00....	Oct. 1, 1889	Oct. 1, 1904..	4½ ..	4,500.00
150,000.00....	Oct. 1, 1889	Oct. 1, 1909..	4½ ..	6,750.00
150,000.00....	Oct. 1, 1889	Oct. 1, 1914..	4½ ..	6,750.00
175,000.00....	Oct. 1, 1889	Oct. 1, 1919..	4½ ..	7,875.00
100,000.00....	July 1, 1892	July 1, 1917..	4½ ..	4,500.00
300,000.00....	Oct. 2, 1893	Oct. 2, 1903..	4½ ..	13,500.00
\$1,150,000.00				

"In return for this expenditure of \$1,150,000 the gas plant has paid from its earnings only \$100,000 in dividends to the city. This money was used each year to pay a part of the interest on the bonds:

	Totals.
Sept. 3, 1892.....	\$ 20,000.00
May 27, 1893.....	\$20,000
Oct. 24, 1893.....	10,000
Dec. 30, 1893.....	10,000
	40,000.00
Mar. 19, 1894.....	15,000
Oct. 15, 1894.....	10,000
	25,000.00
Mar. 26, 1895.....	10,000
Apr. 3, 1895.....	5,000
	15,000.00
	\$100,000.00

"Thus it was that the statements of January 1st, 1896, showed an invested debt of more than a million dollars not even paying the interest on the bonds outstanding.

"The winter of 1896 disclosed no untouched resources; rather, in fact, the supply of gas again became noticeably deficient. Later in the year, however, new territory in Ottawa county, Ohio, was developed, and from this field a pipe line was constructed to the city, so that the gas was turned on with satisfactory results in February, 1897. But in another year the supply became less and less sufficient, with the inevitable result that the municipal gas plant soon lost nearly all its patrons and maintained only a desultory existence through 1898 and 1899. Finally in the latter year all that part of the gas plant outside of the limits of the city of Toledo (including territory loaned and leased, pumping stations, pipe lines, telephone lines, etc.) was sold to the Kerlin Brothers for \$102,000. As the city then had no gas to supply its lines the trustees entered into a contract with the Kerlin Brothers Company for a supply at twenty cents per 1,000 cubic feet. Under this contract gas was furnished the city until January 1st, 1901, when the supply was discontinued.

"By the receipt of \$102,000 for the outside portion of the gas plant the city was able to pay the only issue of bonds that have become due, \$100,000, on October 1, 1899. Some months later the distributing lines inside the city were leased to the Toledo Gas-Light & Coke Company for the insufficient sum of \$6,500 a year. And this annual income of \$6,500 is all the returns that the city of Toledo receives for its expenditure of two million of dollars to establish a municipal gas plant—the grand spectacle of a magnificent failure.

"Today (January 1, 1903) the natural gas used in Toledo is furnished by the Northwestern Ohio Natural Gas Company (controlled by the Standard Oil Company), who secure it from the fields of Fairfield and Hocking counties, Ohio. This supply is obtained from the Clinton formation and is sufficient for all normal occasions; on extremely cold days, however, the small quantity still obtained in the Wood and Hancock county fields is turned into the mains leading to Toledo, so that even at the present time some gas is secured from the Trenton rock of Ohio. The latter formation also furnished the supply of the municipal gas plant as long as it continued in operation. The cost of the fuel has steadily advanced from 12 cents per 1000 cubic feet in 1888 to 30 cents in 1903."

Fostoria, lying a short distance northeast of Findlay, drilled a test well in the summer of 1885, but this was a failure, though it made a showing of both oil and gas.¹

Another well was drilled a year later. After having been shot with a heavy charge of nitro-glycerine it made a fair showing of both oil and gas, but neither in commercial quantity. A third well was drilled west of the city but without noteworthy success. Encouraged by these failures the Northwestern Ohio Natural Gas Company piped the city, giving the inhabitants their first experience with natural gas. This, however, did not boom the place, and to accomplish this free gas was necessary. Accordingly the legislature was asked and granted the municipality the right to issue bonds to the amount of \$35,000 to lease territory, drill wells, lay pipe, etc. Public-spirited citizens raised \$25,000 additional to assist in the work. The territory leased lay principally in the townships west of the city. This commanded a high rental, adding materially to the city's expense. An ample quantity of gas was soon secured, and the city at once began to feel the desired wave of prosperity. As in other gas towns, glass became the principal industry, but the fuel was used for numerous other purposes. Dr. Orton estimated the quantity of gas used by these factories to have been at least 7,000,000 cubic feet per day.²

Tiffin's experience was similar to that of Fostoria. The first well reached the Trenton in January, 1886, and yielded a small quantity of oil and gas as well as salt-water. The result here was merely sufficient to

¹*Geol. Sur. of Ohio*, Vol. VI, p. 192-3.

²*Ibid*, First Ann. Rept., 1890, p. 190-2.

insure further exploration, and a second well reached the Trenton in October of the same year.¹ This yielded both oil and gas in small quantities, and should be classed as an oil well. Other wells were drilled with similar results, and by 1888 the citizens of Tiffin had reached the conclusion that they must look elsewhere for their gas supply. A branch of the Northwestern Ohio Natural Gas Company had already entered the city and was supplying gas to residences and factories, but here again the company was looking after its own interests rather than those of Tiffin. The usual result followed—an agitation for a municipal natural gas plant to furnish free or practically free gas to factories. The legislature granted the city the authority to issue bonds, and the gas trustees purchased, at an exorbitant rate, the gas rights on lands in Wood county.² By 1890 the city had expended over a quarter of a million of dollars on this enterprise, and since the gas was furnished free to factories it is apparent that the income to the city was very small. However, free fuel secured the desired manufacturing establishments, and consequently the city secured indirectly what it could not directly.

Several towns or cities which had failed to secure gas in the underlying rocks, and which did not drill wells and pipe the gas from a distance, were supplied by the Northwestern Ohio Natural Gas Company to which reference has already been made several times. This corporation supported as it was by the great resources of the Standard Oil Company, was able to work on a scale which no other company could do. Very early in the history of the field it secured the best territory in Wood and Hancock counties on relatively easy terms. This it developed in the best manner known, and piped the fuel as far north as Detroit, and as far east as Sandusky. As a rule the rates charged did not permit the fuel's use in factories, and this of course, extended the duration of the supply.

Besides the places named a number of much smaller towns and villages in Hancock, Wood, Sandusky, Seneca and Ottawa counties have enjoyed natural gas. This has usually been derived from small wells close at hand, and since the quantity was not adequate to attract factories the life of the wells has been greatly extended.

PRESENT CONDITION OF THE TERRITORY REVIEWED.

This can be stated in a few words. The early failure of gas at Findlay has already been noted. Leasing territory and drilling wells in the northern part of the county renewed the supply, but only postponed for a brief period the fatal day when gas for everybody and all purposes must end. Early in the nineties the larger factories could no longer be supplied; next the smaller ones were dropped, and at present the use of the fuel is restricted to domestic purposes.

¹*Geol. Sur. of Ohio*, Vol. VI, p. 197-201.

²*Ibid.*, First Ann. Rept., 1890, p. 186-190.

From 1887 to 1889 a large number of manufacturing industries were induced by offers of free gas to locate at Findlay. These included fourteen glass houses and several iron and steel works. A large number of the glass factories were absorbed by the United States Glass Company, and then abandoned when the gas supply became inadequate. Two factories burned and were not rebuilt. At least four abandoned their plants, and rebuilt in Indiana where gas was more abundant. With several exceptions these glass companies had little or no capital, but were dependent on the bonuses furnished by the town for the capital necessary to run their plants. With the failure of gas these companies were left practically bankrupt.

The Wetherald Rolling Company which had come with the boom, left for Indiana in 1892. It employed 200 men. The Salem Wire Nail Company, employing 300 men, sold out to the American Wire Nail Company, but the plant burned and was not rebuilt. Rounds Chain Works, the Ohio Lantern Factory, the American Nail Machine Company, and a number of smaller establishments abandoned their works because of the failure of gas.

The supply of gas in 1902 was derived principally from Cass and Marion townships, one of which lies east and the other north of Findlay, but a few wells are scattered over two or three other townships. The number of wells on which the city relied during the summer of 1902 was about 85. Others are drilled from time to time, and in this manner the supply is maintained. Probably the very best wells now drilled do not have an open flow exceeding 1,000,000 cubic feet per day, while the available supply is only a fraction of that. It is entirely safe to state that less than a half dozen of the large wells of 15 years ago would more than balance the 85 which now reluctantly yield a scant supply. Besides the Findlay wells, the Kenton Gas & Electric Company has 18 wells in Jackson township, and the Northwestern Ohio Natural Gas Company has a small number scattered over the county.

Wood county duplicated Hancock's record. As has already been stated the rock pressure at Bowling Green had fallen to 100 pounds per square inch in 1890, and that marked the end of gas in large volume for that part of the territory. The great Bloom township field lasted longer, largely because it was in the control of a corporation which well knew the limited supply and used all methods to prolong the life. Such cities as Fostoria and Tiffin soon found themselves with a supply totally inadequate to meet the demands of the industries which had been attracted to them by the offer of free gas. Later the great Northwestern Ohio Natural Gas Company also met the same fate. In 1902 this corporation still had about 45 wells in Wood and Hancock counties, but the fuel obtained was barely sufficient to supply power for two pumping stations of the Buckeye Pipe Line Company. At the time mentioned the only villages supplied with gas

from Wood county were Bairdstown and Bloomdale. To such proportions have the great Hancock-Wood county gas fields shrunk!

Among villages in adjacent counties that still have an adequate supply, in whole or in part, may be mentioned Oak Harbor and Genoa in Ottawa county; Gibsonburg and Burgoon in Sandusky county; Kansas in Seneca county. Doubtless this list might be enlarged, but the quantity of fuel consumed in this manner is small.

THE ST. MARYS NATURAL GAS FIELD.

On July 26, 1886, a well was completed at St. Marys, Auglaize county, the result being a small flow of both oil and gas. The well was torpedoed later and the production increased, but the most that can be said for this test was that it demonstrated the presence of the desired fuel. The second well was a total failure, but the third one produced sufficient oil to warrant rigging for this material.¹ Early in 1887 valuable gas wells began to be found, the first of which located on the Axe farm was completed March 23, and three weeks later had an open flow exceeding 2,000,000 cubic feet per day. Other wells were completed with similar results. The rock pressure of the field was about 350 pounds per square inch. St. Marys township contained the best territory, but small areas in the adjoining townships of Washington and German also yielded gas.

From Auglaize county the belt extended southwest into Mercer, including parts of Franklin, Marion and Granville townships. The first named township contained the best wells, the largest of which had an initial open flow of 10,000,000 cubic feet in 24 hours. It is doubtful if this figure was exceeded anywhere in what is here called the St. Marys field. It appears, in fact, from data obtained at this late day that wells exceeding one-half the figure just given were rare. This field extended northeast and southwest, its length being nearly 20 miles. Work in Mercer county began in 1886, the first well having been drilled at Celina. This made merely a show of oil and gas, and a second well completed a few weeks later gave still less encouragement. In November, 1886, a well was completed near St. Henry, Granville township, and when measured about four months later was flowing over 2,600,000 cubic feet per day. Early in 1887 a well was completed on the Doenzes farm in Franklin township with still more favorable results, the production exceeding 4,600,000 cubic feet in 24 hours.² With such results work progressed rapidly, and the quantity of fuel secured was such as to warrant laying lines to adjacent cities and towns.

The history of the field from this point was similar to that around Findlay. However, the wells were smaller, and consequently there was less opportunity for the excitement and speculation that prevailed farther

¹*Geol. Sur. of Ohio*, Vol. VI, p. 254-8.

²*Ibid.*, p. 258-62.

northeast. Perhaps, too, the experience gained in that territory had a sobering effect in this.

By authority of the legislature, St. Marys was permitted to bond itself for \$32,000 to construct and operate a natural gas plant. A block of 1,100 acres lying near the town was leased at a low rental, and a number of good wells secured. Fuel was supplied for domestic purposes at one dollar a fire per month, and two factories were supplied without charge.¹ According to data furnished by J. D. Simpkins, Superintendent of Schools, the town incurred an indebtedness of \$24,000, and this was subsequently paid by receipts from the sale of the plant. The place discontinued the use of natural gas from the Trenton of Ohio, in 1893.

The Lima Natural Gas Company derived its principal supply of gas from St. Marys township, where it had about 7,000 acres of land leased. The company began piping gas to Lima in 1887 and for a short period had an ample supply, but the flow decreased gradually and gave out entirely in 1894. Since then the fuel has been obtained from Indiana. In the fall of 1902 the rate was 25 cents net per thousand cubic feet, but if the consumer furnished the meter the rate was five cents lower.

A number of wells drilled in the vicinity of Van Wert promised so well that a line was laid to the town in 1888. However the supply was not up to expectations, and after \$50,000 had been expended in making tests, the trustees leased territory in Franklin township, Mercer county, and laid a line to Van Wert, 31 miles away. Good wells were secured, and soon the town had an adequate supply. When this territory gave out the trustees again devoted their energy to developing gas lands in their own county. At the present time (August, 1902) the supply is derived from six wells in Ridge township. The first of these was drilled in 1894, and other wells have been put down from time to time since that year. In April, 1902, the total open flow of the wells was reported at over 2,800,000 cubic feet per day. The rates charged for the fuel are 25 cents per thousand, if paid before the 10th of the month, after that 30 cents. The company pays the landholders a royalty of \$50 a year for each well.

In 1888 the Wapakoneta Natural Gas Company was organized, its object being to supply that town with fuel in order that it might not be at a disadvantage with neighboring places. The plant was constructed and operated by citizens of Wapakoneta, who leased territory in St. Marys and Washington townships. Owing to the late day at which the wells were drilled, the rock pressure was comparatively low at the start, and this of course diminished the life of the wells.² Besides the places named a number of smaller towns and villages were supplied from this field.

Celina, the county seat of Mercer county, was supplied by the Celina Light & Fuel Company, whose territory lay chiefly in Franklin township,

¹*Geol. Sur. of Ohio*, First Ann. Rept., 1890, p. 157.

²*Ibid.*, Vol. VI, p. 160-1.

Mercer county. The fuel was used for domestic purposes, and also for factories, the principal industry being glass.

While the company was a private affair, an arrangement was made between it and the city council by which free gas was to be furnished for the two glass houses during a period of five years. The result of the heavy demands was the cry insufficient gas, the rock pressure of the field having fallen from 390 pounds in 1887 to 240 in June, 1890.¹

The Mercer Natural Gas Company was by far the largest one operating in Mercer county. Its principal territory lay in Franklin township, but it had wells in Auglaize county as well as in Mercer. The company's lines supplied Sidney, Piqua, Troy, Springfield, Dayton, and a number of smaller places. It is hardly necessary to state that this corporation did not furnish free gas to factories, and consequently that the places named did not enjoy the boom that Findlay and adjacent towns did. The fuel was used economically and its life prolonged to the farthest limit. It is interesting to note in this connection that these places are now, in part at least, supplied from the Sugar Grove field, a line having been laid from that territory to Springfield, where it connects with the old lines of the Mercer Natural Gas Company.

The city of Urbana, anxious to enjoy the prosperity that seemed to follow free gas, began by testing the Trenton limestone in that vicinity, and finding it barren of the desired fuel, turned to the territory in Auglaize and Mercer counties. The course from this time was of the usual nature; the legislature passed an act (1889) permitting the citizens to vote on a proposition to bond the municipality for a quarter of a million of dollars to lease territory, drill wells, lay mains, etc. The proposition appealed to all, for out of a vote of 1,240 only 27 were recorded against it.²

Lands were leased in Marion township, Mercer county, and the trustees soon had a fine supply of fuel. However, the town did not enjoy the manufacturing boom that it had looked for. This resulted from several causes: (1) The late date (1890) at which the city was prepared to furnish gas; (2) the remoteness of the producing territory; (3) the demonstrated brief life of gas wells. However, the municipality was supplied for several years with the best fuel known, and later when its territory gave out, the lines were filled from the Sugar Grove field. The later history of natural gas in Urbana is given below; the data having been supplied by I. N. Keyser, Superintendent of Schools:

"The city of Urbana was bonded for \$250,000 to make the necessary preparations to supply gas. The supply was derived from the St. Marys field, and at first the pressure was sufficient to yield a good flow. After four years the field pressure ran down so that it could no longer force the

¹*Geol. Sur. of Ohio*, Vol. VI, p. 162-4.

²*Ibid.*, p. 166-70.

gas to Urbana—47 miles distant—and then pumping stations were constructed. This prolonged the life of the plant four years longer, and by that time the supply was so small that the territory was abandoned.

"The plant was leased and later connections were made with the Sugar Grove field which now furnishes the town fuel at 25 cents per thousand cubic feet.

"The income from the plant was not sufficient to pay off the bonds entirely, so a sinking fund was established and the debt rests easily.

"The gas was piped to Urbana in 1890, when experience was limited in matters of gas well permanency. Then, too, the trustees desired to furnish gas as cheaply as possible, fixing the price at 11 cents per thousand cubic feet. Later this was increased to 15 cents, and when the plant was leased the price was first fixed at 20 cents and now (December, 1902) is 25 cents.

"Had the value of the fuel been thoroughly appreciated at first and the price set at 20 or 25 cents, I doubt not that the city ownership would have been profitable. As it is, what money was spent to make up deficits is money, in part, that was saved by cheap fuel."

Greenville, Darke county, proceeded in a manner similar to Urbana. Under authority of the legislature the town bonded itself for \$130,000 to procure and operate a natural gas plant.¹ Previous to this a company had leased a tract approximating 1,200 acres in Granville township, Mercer county, and drilled two wells on it. The trustees of the new plant bought this property and drilled additional wells with fair success. A line 19 miles in length was laid to the town, and soon there were 2,000 fires supplied with the new fuel. The gas was used on a small scale for factories, the largest consumer having been a tile mill.

THE DISCOVERY AND DEVELOPMENT OF THE OIL FIELDS IN NORTHWESTERN OHIO.

It is seen from what has already been said that the pioneer deep wells in northwestern Ohio had for their object natural gas, oil having been an incidental product, and since it obstructed the flow of gas through the lines, was at first looked upon with disfavor.

The oil industry in this part of the state had its beginning in the autumn of 1885. It is difficult to decide which county should have the credit of the first oil well, since many produced both oil and gas, the relative quantities being such that some call them oil wells while others class them with gas wells.

Allen county was the third to test the Trenton limestone, and like the earlier work in Hancock and Wood counties the object was natural gas. The well was located at Lima, and was completed April 1, 1885. When the Trenton rock was struck it yielded little or no gas, but in its stead a

¹*Geol. Sur. of Ohio*, Vol. VI, p. 170-2.

small quantity of oil—a great disappointment to the parties interested. After having been shot with rack-rock the well was pumped, yielding about 18 barrels of oil per day.¹ The product was looked upon with much disfavor because of its density, color, and particularly its odor. The great fields of Pennsylvania were in sandstone, while the oil in question was derived from a limestone, thus further prejudicing the new field. However the interested parties did not cease work even if the product was apparently of very low quality, and in the fall of 1885 completed a well which had for its object testing the underlying rocks with reference to oil production. When put to pumping it yielded forty or more barrels per day, and during the early months of 1886 averaged 26 barrels each 24 hours. Oil from this well was sent to large refineries, and the results of tests made gave great encouragement to the producers. This really marks the beginning of the industry in Allen county. Not until the following year, however, was any considerable progress made in the development of the territory.

As has already been stated gas was discovered at Findlay in November 1884, and though the flow was small it was adequate to make certain further tests. Almost from the start oil appeared in these wells, but in very small quantities. Well No. 4, completed May 28, 1885, was the first one drilled in this field that may be classed as an oil rather than a gas well. At first, however, it produced over a million cubic feet of gas per day, but during the closing months of 1885 it flowed about five barrels of oil each 24 hours.² In January, 1886, the production of gas dropped suddenly, owing to the influence of the Karg well, and at the same time the yield of oil increased from five to fifteen or more barrels per day. Well No. 8, completed November 6, 1885, was drilled primarily for oil, the first one sunk for this purpose in the county. The Trenton was struck at 1,265 feet, and drilling continued until a depth of 1,320 feet had been reached. The well was then shot with 100 quarts of nitro-glycerine, and began ~~flowing oil at~~ the rate of 300 barrels per day. The production decreased rapidly to 35 barrels per day.³ Dr. Orton considered this the first of the oil wells in Hancock county, and that the petroleum industry in that territory began with this.

In the summer of 1886 a well was drilled at ~~North~~ Baltimore, Wood county, the object being, as in all these pioneer wells, natural gas. At seventeen and one-half feet in the Trenton, oil was found. After having been shot with 40 quarts of nitro-glycerine, the well was tubed, and began flowing from 12 to 15 barrels of oil per day. In a short time, however, the production decreased greatly and then the well was abandoned. The oil was lighter (41 degrees B.) than that found at Lima, and this encour-

¹*Geol. Sur. of Ohio*, Vol. VI, p. 166.

²*Ibid.*, p. 122-4.

³*Ibid.*, p. 126.

aged the producers to such an extent that they began leasing territory in the vicinity of North Baltimore with reference to the development of an oil field. Later in the year a number of fine wells were secured in the same township (Henry), and from that period rapid progress was made.¹

The year 1885 demonstrated the existence of oil in the Trenton, and in the ensuing year development began rapidly. From the established centers the drill moved out in all directions, and during the same time much testing of the "wild-cat" type was done. The result was that in a short period the important fields had been outlined, and by far the greater part of the work done since has been in developing that territory.

The following statistics, compiled from the Mineral Resources of the United States, tell plainly the growth of the industry.

Production of the Trenton Limestone in Ohio from 1886 to 1901.

Year.	Barrels.
1886	1,064,025
1887	4,650,375
1888	9,682,683
1889	12,153,189
1890	15,014,882
1891	17,315,972
1892	15,169,507
1893	13,646,804
1894	13,607,844
1895	15,850,609
1896	20,575,138
1897	18,682,677
1898	16,590,416
1899	16,377,174
1900	16,884,358
1901	16,176,293

The production in 1885 was comparatively small.

The following table gives the annual output of the United States from the beginning of the industry in 1859 to 1901, and that of Ohio beginning with 1876.

Production of Oil in Ohio and the United States from 1860 to 1901.²

(Barrels of 42 Gallons.)

Year.	Ohio.	United States.	Year.	Ohio.	United States.
1859		2,000	1881	33,867	27,661,238
1860		500,000	1882	39,761	30,510,830
1861		2,113,609	1883	47,632	23,449,633
1862		3,056,690	1884	90,081	24,218,438
1863		2,611,309	1885	661,580	21,858,785
1864		2,116,109	1886	1,782,970	28,064,841
1865		2,497,700	1887	5,022,632	28,283,483
1866		3,597,700	1888	10,010,868	27,612,025
1867		3,347,300	1889	12,471,466	35,163,512
1868		3,646,117	1890	16,124,656	45,823,572
1869		4,215,000	1891	17,740,301	54,292,655
1870		5,260,745	1892	16,362,921	50,509,657
1871		5,205,234	1893	16,249,769	48,431,066
1872		6,293,194	1894	16,792,154	49,344,516
1873		9,893,786	1895	19,545,233	52,892,276
1874		10,926,945	1896	23,941,169	60,960,361
1875		12,162,514	1897	21,560,515	60,475,516
1876	31,763	9,132,669	1898	18,738,708	55,364,233
1877	29,888	13,350,363	1899	21,142,108	57,070,850
1878	38,179	15,396,868	1900	22,362,730	63,362,704
1879	29,112	19,914,146	1901	21,648,083	69,389,194
1880	38,940	26,286,123			

¹*Geol. Sur. of Ohio*, Vol. VI, p. 227-8.

²Note.—The production given for the United States for the year 1875 includes all prior to 1876 in Ohio, West Virginia and California.

The Following Table Gives the Quantity and Value of Oil of the Three Producing Areas in Ohio from 1895 to 1901.

Year.	Northwestern Ohio.		Southeastern Ohio.		Mecca-Belden.		Total.	
	Product (bbl.)	Value	Product (bbl.)	Value.	Prod.(bbl.)	Value.	Product (bbl.)	Value.
1895	15,850,609	\$11,372,812	8,698,248	\$5,018,201	1,376	\$ 8,229	19,545,283	\$16,389,242
1896	20,575,138	13,723,617	8,365,365	3,966,924	666	2,897	23,941,169	17,693,498
1897	18,682,677	8,967,685	2,877,193	2,262,193	645	3,120	21,560,515	11,232,998
1898	16,590,416	10,244,582	2,147,610	1,957,010	682	3,618	18,738,708	12,205,210
1899	16,377,174	14,718,985	4,764,135	6,243,075	799	4,244	21,142,108	20,966,304
1900	16,884,358	16,673,304	5,476,089	7,406,734	2,283	11,563	22,362,730	24,091,601
1901	16,176,293	13,911,612	5,470,850	6,619,342	940	2,617	21,648,083	20,533,571

WOOD COUNTY.

This has the largest area of oil producing territory of any county in the state. It includes two extensive belts; one on the eastern, the other on the western side of the county, but in the southern part the two are connected by a narrow strip. The western area is the larger; in fact it is the most extensive pool that has been or ever will be found in Ohio. Continuing south it enters Hancock county, where it covers a large area. The eastern belt extends into Sandusky county and the northwestern corner of Seneca. Probably no other county in the state has had so many deep wells drilled in it as Wood. Almost every section has had at least one test made on it, and on some they may be counted by the score. This has demonstrated the parts that contain oil, and it may be that with higher prices for the crude product, territory which cannot now be regarded as productive may become of value; just as some territory, which was not regarded worth developing fifteen years ago, is now highly prized..

Next the several townships will be considered in detail, taking first those on the western side of the county, and later those on the eastern.

Middleton Township.—The oil fields in this township form a strip from one-quarter to a mile in width, which runs nearly due north and south through "river tract sections" 46, 47, 48, 49, 50 and 51; and sections 14, 15, 21, 22, 23, 26, 27, 33, 34 and 35.

An effort was made in the summer of 1902 to extend the arm farther north in this township, but without success; a well on the "river tract" section 52 was dry, and the same is true of a well drilled about three miles farther north.

In the eastern part of Middleton there is a small pool of oil, now nearly exhausted. Formerly it extended from the northern half of section 28 through 21 and 16, and then into Perrysburg township, where it crossed section 33. Now (1902) it consists of two parts; a small pool about one-quarter of a mile square in the northern part of section 28 and a larger one extending northward from near the center of section 21. The territory connecting these two spots was much less productive than the other parts, and this accounts for its comparatively early abandonment. The pool is commonly spoken of as the Dunbridge or Dowling, since it lies near these villages.

Previous to 1890 very little drilling had been done in this township. Test wells sunk about that time in the vicinity of Haskins gave much promise, and consequently rapid progress was made in the development of the pool. Wells now (1902) rarely have a larger production than 10 barrels per day, and the average is only a small fraction of that. Very few are being drilled, and while the number abandoned thus far is small, it will be large in the near future.

The Dowling pool was opened in 1894-5, and at first was regarded as very promising, though the oil was of poor quality. The number of wells

in 1896 was 57 and the combined daily production 350 barrels; in 1902 the number was 86 with a production of only 75 barrels, an average of less than one barrel per well. The pool is rapidly approaching extinction. The gravity of the oil in 1902 was 34 degrees B.

Washington Township.—The only oil territory in this township is found in the extreme northeast corner, and does not exceed 80 acres. This is part of a small spur which leaves the strip in Middleton township, near the village Haskins.

Plain Township.—From Middleton the strip extends south into Plain township where it occupies parts of sections 2, 3, 10, 11, 14, 15, 16, 17, 21, 22, 23, 25, 26, 27, 28, 32, 33, 34, 35 and 36. In the northern part of the township the strip is very narrow, not exceeding in places one-quarter of a mile, but along the southern line it exceeds three miles. The broad portion of the territory encloses a non-productive strip nearly three miles in length, and from one-quarter to one mile in width. Enclosures of this type are common in Wood and Sandusky counties. The entire area of producing territory in this township does not exceed eight square miles.

In 1890 Dr. Orton predicted that an oil field would be developed west of Bowling Green, though at that time the nearest wells were in the southern part of the township, and near Haskins in the township to the north. The terrace extending north from Findlay had been located west of Bowling Green in the county now under consideration, and on this basis oil was predicted. Wells were drilled in this region in 1890-1 with favorable results, and continued progress has been made since. But few wells have been drilled in recent years, and naturally the production is decreasing.

Liberty Township.—A large part of this township is productive. The territory enters as a broad belt from Plain and continues due south across the township, including the whole or parts of sections 1, 2, 3, 4, 5, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 33, 34, 35 and 36, and having an area of about 22 square miles. In the northwestern corner of the township there is an unproductive area. This extends southeast from section 2 through 1, 11, 12, 13, 24 and 25, and then enters Portage township. The barren strip is completely surrounded by oil territory, and has been frequently tested, the result being salt-water and a small quantity of oil.

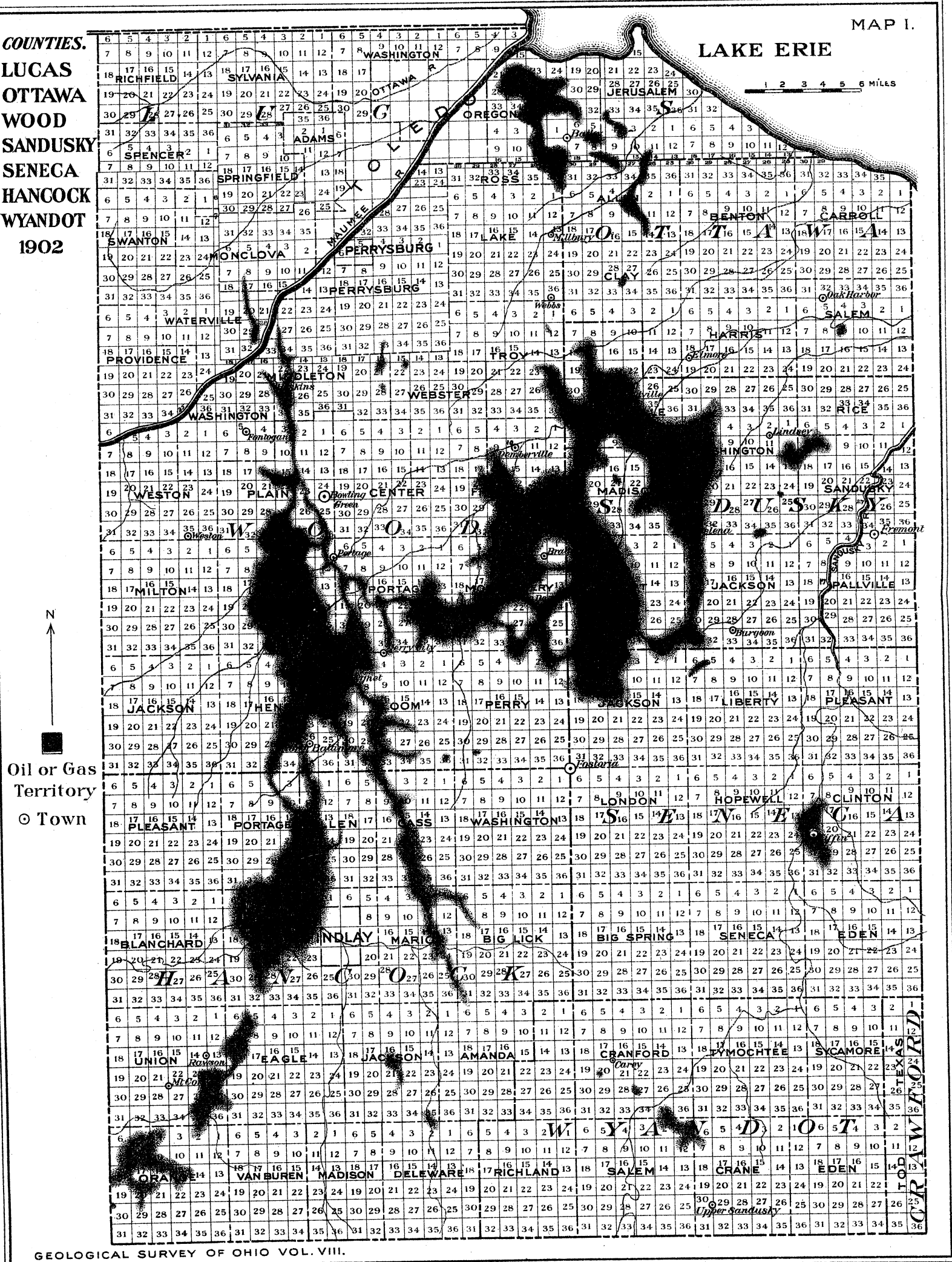
In 1890 the eastern sections of the township were being rapidly developed, but the presence of a large reservoir of salt-water seemed to cut off production further west. Later, however, it was found that the water could be controlled, and then the condemned territory began to be drilled. This has since demonstrated itself to be one of the most valuable parts of the county.

Henry Township.—From Liberty the producing territory extends south entirely across the township under consideration and then continues into Hancock county. In the northern part of the township the territory

**LUCAS
OTTAWA
WOOD
SANDUSKY
SENECA
HANCOCK
WYANDOT
1902**

LAKE ERIE

1 2 3 4 5 6 MILES



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is three miles wide and this dimension continues south of the middle of the township where two enclosed non-productive areas are found. The sections producing oil include the whole or part of 1, 2, 3, 4, 9, 10, 11, 12, 13, 14, 15, 16, 21, 22, 23, 24, 25, 26, 27, 28, 33, 34 and 35.

As has already been stated this was the first territory developed in Wood county. Since 1890 the outlines of the producing areas have undergone little change, and the large amount of drilling done since that time has been to develop these areas. However development in this direction has reached its limit, and the time when the township will cease to be included in the oil fields will be determined by the duration of wells already drilled.

Portage Township.—The oil territory in this township connects the two larger pools of Wood county, as is plainly shown on the map. The most striking feature is the barren tracts enclosed or partly enclosed by producing territory. The productive area includes the whole or parts of sections 6, 7, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, but while the area is scattered over the larger part of the township, it does not exceed ten square miles.

The time of the development of the township was similar to that of Bloom, though apparently a little earlier. The barren tracts have been thoroughly tested, but give no promise of becoming productive territory. A few wells are still (1902) being drilled in the township, some of the best having been secured on lots in the village Portage.

Bloom Township.—This township, lying east of Henry and south of Portage, contains part of the pool found in the western half of Wood county. The productive territory lies on the west side of the township, and is very irregular in outline. It includes the whole or parts of sections 4, 5, 6, 7, 8, 9, 16, 17, 18, 19, 20, 21, 22, 23, 26, 27, 28, 29, 31, 32, 33, 34, 35. Besides this a small pool of perhaps 60 acres is found in section 36 in the extreme southeast corner of the township.

Formerly Bloom township was the center of the natural gas industry in Wood county. When the flow of gas became weak, oil appeared, and in this manner some gas wells became producer of oil. Later the territory was re-drilled, this time with oil in view. In 1890 the number of oil wells in the township was small, but a little later the Henry township field was extended into the western margin, and the Portage township field into the northern margin, and thereafter the territory was rapidly developed. During the past year (1902) the principal development was in the southern part of the township near the villages Welker and Bairdstown.

Webster Township.—In 1902 there was only one pool of oil in this township. This had an area of only 100 acres and was situated in the northeast corner of section 22 and the southeast of 15. As may be seen from the map the pool is close to the Dowling, to which the quality of oil is similar.

Troy Township.—Oil territory in this township is small, and is confined principally to the southeast quarter, where it occupies parts of sections 23, 24, 25, 26 and 36. The area of this is about two square miles. It is an extension of the pool lying in the vicinity of Woodville, Sandusky county.

In the northwest quarter of section 12 a very small pool exists. It consisted in 1902 of five wells running in a northwest and southeast line. Another well or two has been drilled in this vicinity with a small degree of success.

Territory in this township began to be developed in 1894-5. The small pool in section 12, referred to above, was opened in 1895; the initial well being reported to have averaged 250 barrels of oil per day during the first month. Its decrease, however, was rapid, and the well was abandoned in 1902. Many other holes were drilled in that part of the township with the hope of extending the pool. One well in this vicinity yielded some gas from the Clinton limestone. Practically no drilling was done in this township in 1902.

Freedom Township.—The southeastern portion of this is oil producing; the territory includes the whole or the part of sections 8, 9, 15, 16, 17, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 32, 33, 34, 35 and 36. Besides this there is a very small area in the extreme northeast corner of the township. All territory in this township is simply an extension from that of Sandusky county.

Montgomery Township.—This township contains the largest area of producing territory in Wood county, all but one of its 36 sections yielding some oil. The territory, however, is quite spotted, a number of barren areas being enclosed by producing territory. Eastward the pool extends into Sandusky county, and westward into Portage township where it is connected by a narrow arm with the territory lying in the western portion of the county now under consideration.

Few wells were to be found in the township in 1890, but active work began about that time. Little testing was being done in 1902, and it seems that not much can be expected from the township in the future. The gravity of the oil is 42 degrees B., about two degrees lighter than most oil secured in Wood and adjacent counties.

Perry Township.—This township contains small areas of oil territory in two opposite corners, the northeast and the southwest. The former includes parts of sections 1, 2, 3, 4 and 12, and extends into Montgomery township on the north and into Sandusky county on the east. The second area referred to above extends as a narrow strip diagonally across section 32, and includes in addition a few acres in 29, 30, 31 and 33. A few small wells have been secured in section 34 also, but none were being operated in July, 1902.

Wells Drilled.—The wells drilled in the county from 1891 to 1899 have been as follows:

	Producers.	Dry.	Totals.
1891	530	92	622
1892	655	77	732
1893	663	97	760
1894	746	139	885
1895	347	40	387
1896	1,411	181	1,592
1897	677	114	791
1898	746	91	837
1899	976	79	1,055
Totals	6,751	910	7,661

This shows that 88 per cent. of the wells were producers and 12 per cent. failures.

GEOLOGY OF THE COUNTY.

The surface of Wood county is either flat or gently rolling. It comprises part of the territory formerly known as the black swamp, a large tract now constituting one of the richest parts of the state, whether considered from an agricultural standpoint or from that of underground wealth. The surface rocks are the Lower Helderberg over the greater portion of the county, but near the central part and along the southern and southeastern borders the Niagara is found. The succession of strata below the surface is shown by the following record of a well at Bowling Green.¹

	Feet.
Drift	8
Niagara limestone.....	162
Thin break (shales).....	
Blue limestone.....	5
Niagara and Clinton limestone and shales.....	108
Medina shales (red).....	47
Cincinnati (Hudson River) shales, blue with thin sheets of limestone.....	462
Utica shales (brown).....	300
Trenton limestone at.....	1,092
Bottom of well at.....	1,648

The sharp fold in the Trenton limestone found in this county has already been reported by Dr. Orton. It is conspicuous as far north at least as Bowling Green, but in the northern part of the county flattens, not being conspicuous thereafter. The size of this fold is well illustrated by the following data:

Plain township, section 36, southwest quarter; Trenton at 1,090 feet; 400 feet west of this the same formation was struck at 1,306 feet, a drop of 216 feet. On the east line of this section the Trenton was found at 1090

¹*Geol. Sur. of Ohio*, Vol. VI, p. 112.

feet, showing that for one-half mile at least east of the fold the rock is horizontal.

On section 26 lying northwest of the last section, the Trenton was found on the east side of the Case farm at 1132 feet, and on the west side of the same farm, one-half mile distant, at 1372 feet, a drop of 240.

On section 23, which lies due north of 29, the Trenton was struck on the P. J. Brown farm at 1153 feet, and 400 feet west of this, on the Isaac Brown place, at 1320 feet, a drop of 167 feet. It is stated by a person well informed on the subject that the strip of producing territory extending from sections 22 and 23 north past Haskins lies on this fold, but that the latter is not as marked there as farther south. By reference to the map it will be seen from what has been said that the fold lies one mile west of Bowling Green and not directly beneath it as has been stated.

The following data show the position of the Trenton in Wood county. The first records are from the southern part of the county, along the B. & O. R. R., which in fact was used as a datum line.

Township.	Section.	Drive Pipe.	Casing.	Depth of Trenton in feet.	Feet below sea level.
Perry . . .	32	36 ft.	370 ft.	1154	390
Bloom. . . .	36			1120	360
Bloom. . . .	33	30 "	235 "	1068	321
Bloom. . . .	31	30 "	270 "	1100	364
Henry. . . .	34	28 "	370 "	1171	431
Jackson . .	31	70 "	600 "	1461	740

This shows that the summit of the fold lies on or near section 33 of Bloom township, from which it dips to the east 70 feet in five miles; and westward 110 feet in the same distance, but continuing west the dip increases, so that it amounts to 309 feet in 9 miles.

Six miles north of the preceding line the Trenton is found at the following depths:

Township.	Section.	Depth of Trenton in feet.	Feet below sea level.
Perry	1	1200	493
Bloom.	6	1023	322
Henry.	1	1153	450 (approx.)
Henry.	3	1167	467 "

This shows that Cygnet is on or very close to the sharp fold to which reference has already been made. East from Cygnet the dip is fourteen feet per mile.

Three miles farther north the following data were secured:

Township.	Section.	Trenton.	Below sea level, (approximate feet.)
Montgomery	15	1200	500
Portage	18	1135	445
Liberty	24	1260	560
Liberty	20	1250	550
Liberty	19	1300	600

From what has been said it is apparent that in Wood county the Trenton limestone makes considerable change in position. The most prominent is the sharp fold running north and south, west of the middle of the county. In fact this is one of the most abrupt folds known in Ohio. Westward from this disturbance the rock dips to the west 22 feet per mile for perhaps five miles, and then increases to 35 feet. On the east side of this fold the rock lies apparently flat, but careful measurement shows that it dips to the east. In the northern part of the county the rock dips to the north. The Trenton lies highest in Bloom township on the south side of the county.

It was formerly thought that when the Trenton had been penetrated 50 feet without securing the desired fuel, hope must be abandoned. Indeed by far the larger part of oil secured has been derived from depths less than that just given. However good producers have been found farther down. One of the first wells to help break down the early view was the Ducat, drilled in Liberty township, Wood county, about 1887. The story of this well reads like a romance. A poor German had secured a twenty acre lease in what was regarded "wild-cat" territory. He had a very poor string of tools, putting in these and the lease every dollar that he could command. When he reached the Trenton rock it yielded no oil, and the driller became greatly discouraged. However, he had staked all—and consequently was compelled to drill deeper, hoping for the best. At 50 feet a strong flow of gas was found, but no oil. The outlook now was practically hopeless, in view of the results in other fields. At this stage a representative of the Standard Oil Company, who has furnished these data, chanced to be driving by. Hitching his horse he walked to the derrick, and found the facts as just related. The driller was still at work, but with so little hope that he offered to sell the lease and well at cost,

about \$2,500. Not caring to add to the discouragement by refusing, the visitor promised to consider the proposition and drove away. A few minutes later, when only a fraction of a mile from the well, he heard a loud report, and looking back saw a solid stream of oil flowing from the well, and rising higher than the derrick. He at once returned to the well, offering to purchase it on the terms which the driller had proposed a half hour before, but now it was the latter's opportunity to decline.

The giant was not gotten under control for 48 hours, and during all that time flowed over the derrick top. By actual guaging it later produced at the rate of 10,000 barrels per day. When it was flowing over the derrick the production was probably several times larger.

The owner kept the well about six months and then sold it for \$10,000. The well changed hands several times, finally becoming the property of the Standard Oil Company. Another hole was drilled on the same lease, but it is reported to have never exceeded 15 barrels per day. The driller leased other tracts and made an immense fortune. He then bought a good farm on which he has since resided.

As has already been stated most of the oil from northwestern Ohio has been obtained from depths of less than 50 feet in the Trenton rock. Nearly always the top of the rock, called the cap, is free from both oil and gas. Immediately below this, these fuels may be expected. Sometimes they are found at about the same depth in the rock over considerable areas, but at other times the depths change rapidly. An illustration of this is found in Bloom township, where a driller of wide experience reports no definite horizon in the rock at which oil or gas may be expected. Within a distance of a few rods this may vary 50 feet.

One of the comparatively recent developments in the Trenton rock is the deeper pays. Sometimes two are found and at others three. The positions of these are made clear by the following data:

Township.	Section.	Top of Trenton. Feet.	First Pay. Feet.	Second Pay. Feet.
Bloom .	31	1100	1142	1250
Bloom .	33	1068	1108	1268
Bloom .	26	1103 { (gas)	1174	1233 (gas)
		(oil)	1222	1273 (oil)
Bloom .	23	1099 { (oil)	1176	1265 (oil)
		(gas)	1212	1310 (oil & gas)
Henry .	34	1171	1195	1225

Near Bairdstown, while the first pay had the largest initial production, the second one promises to have the longer life. The upper and lower pools are by no means coextensive. The lower one has not been

reported north of Bloom, Henry and Liberty townships. The third pay was not discovered until about 1900. In parts of Wood county many wells are being drilled deeper with the hope of striking the second or third pay.

Another characteristic of the Trenton in the vicinity of Welker and Bairdstown is the presence of numerous crevices. These are reported in nearly every oil field, but are usually looked upon with much suspicion by geologists. In this field, however, the crevices are so persistently reported by drillers and operators that there seems no reasonable doubt of their existence. Further, fragments blown up by torpedoes sometimes show a honey-comb structure, the openings having a length of several inches. The surface of these cavities indicate that the work has been done by solution. The larger crevices have probably been made in the same manner by enlarging cracks and joints. The depth of crevices vary greatly, usually ranging from a few inches to a foot or two, but occasionally much larger depths are reported. As will readily be understood these openings are much dreaded by drillers; when the crevice is not vertical the hole is in danger of becoming crooked, and the tools are liable to become fast.

It appears that many of the largest oil and gas wells were secured in localities where crevices are numerous. Such wells commonly begin with a very heavy flow, and this may be long maintained. There are many cases, however, where such wells have been exhausted in a few months, the theory being that the crevice has been emptied. Sometimes when extra large producers have been secured, a rival company, owning an adjacent lease, drills on it with the hope of securing part of the oil or gas. If this is not secured when the Trenton rock has been penetrated to a depth of perhaps 50 feet, a heavy charge of nitroglycerine is used to break into the crevice. It is believed that efforts of this kind have been failures more frequently than successes.

Occasionally oil and gas are found in rocks other than the Trenton. On section 51, "Maumee river tract," a well drilled in the autumn of 1901 found oil in the Clinton limestone, the production being 3 barrels per day in the following July. In fact it is not uncommon to find a small quantity of oil and gas in this formation.

The great shales lying below the Clinton also produce occasionally both oil and gas, but as a rule the duration of such is brief. A well in Bloom township had an initial production of 300 barrels per day, the oil having been secured at a depth of 300 feet in the Cincinnati shales. This produced between 4,000 and 5,000 barrels of oil, and then giving out, the hole was extended to the Trenton. A well near Waterville found oil at the same horizon, the production starting at 125 barrels per day. The total yield, however, did not exceed more than 2,000 barrels.

Barren Tracts Enclosed by Producing Territory.—This is one of the characteristics of the county. As may be seen from the map these vary in size, position, and direction of extent. Wells drilled in them frequently yield some oil, but rarely in paying quantities. The cause for their existence is not understood. The rock lies at about the same elevation as that of the surrounding producing territory, thus apparently precluding the idea that the barrenness results from the position of the rock. However in some cases the rock lies a little lower, so that it is possible that position may be in part at least the cause of the absence of oil. The fact that such tracts sometimes contain large quantities of salt-water lends weight to this idea. To the writer it seems more probable that the absence of oil results from changes in the texture of the rock, by which it becomes too compact to serve as a reservoir. Possibly this may follow from a change in the rock's composition, the carbonate of magnesia having decreased and that of calcium correspondingly increased. However tests have not been made to prove or disprove this suggestion. It is not an easy matter at this late day to procure samples of Trenton from this territory.

Size and Duration of Wells.—This county may be considered the richest part of the Trenton limestone field. In making this statement, extent of territory, size of wells, and period of production is considered. Probably the largest well in the county was the Ducat, whose history has already been given. There were several wells having an initial production of 5,000 or more barrels of oil during the first 24 hours. One located a mile north of Hammonsburg in Henry township, is reported to have produced 15,000 barrels of oil per month during a year. One of the most recent of the large wells was drilled in 1893, and was located on the P. J. Brown farm, section 22, Plain township. After having flowed openly during 15 hours, the well was gotten under control, and then filled a 250 barrel tank in 52 minutes—a rate exceeding 6,000 barrels per day.

The production of the county, however, was not derived from these large wells, but from those having an initial production ranging from perhaps 25 to 500 barrels. Wells drilled in recent years have been relatively small; those completed in 1901 rarely exceeded 40 barrels, while those drilled later were still smaller. In the summer of 1902 the wells in the western half of the county averaged about 3 barrels each per day, but those on the eastern half were smaller, averaging less than two barrels each.

The average life of wells—a question frequently asked—is difficult to state. The territory, however, is long lived, as much so as any in north-western Ohio; and wells having had a heavy initial production (say 500 barrels per day) are said to produce on the average from ten to twelve years. Gaugers report the average decrease in the production of a well to be about $12\frac{1}{2}$ per cent. each year. The number of new wells being

drilled in this county in 1902 was at the rate of two for each one abandoned. It is reasonable to expect that the ratio of the latter group with reference to the former one will be largely increased during the next few years.

Salt-Water.—No county in the entire Trenton limestone field has been underlain with a greater reservoir of salt-water than Wood. This was a serious obstacle in the days of natural gas, causing the premature death of more than one well. At first the water was regarded as a formidable obstacle to oil development, but it was soon found that the two could readily be separated, and that the principal increase in the cost of production was that arising from pumping the salt-water. Later it was found that after having been pumped regularly the reservoir of water decreased. It was further noted that these wells were very long producers of oil, and consequently they have come into favor. Many wells when completed, have not made a show of oil, but after having been pumped for weeks or months began producing oil. One has been reported as having been pumped 27 months before oil appeared, and later yielded 400 barrels per day. Many claim that the salt-water prevents the wells from paraffining.

The quantity of water pumped from the Trenton in this county has been enormous. During 15 years thousands of pumps have been at work, many stopping for repairs only. As might be suspected the reservoir has been greatly reduced, and at the present time causes much less trouble.

HANCOCK COUNTY.

The Wood county oil fields are connected with those of Hancock by two independent branches. One of these lies on the west side of the county, the other on the east.

The western branch enters the county through Allen and Portage townships and includes a large part of Liberty to the south, having a width there exceeding five miles. The area of this pool is about 43 square miles.

The eastern branch passes from Bloom township, Wood county, into Cass of Hancock, and extends entirely across this township and then enters Marion on the south. From this it extends into Big Lick, and finally into the northern part of Amanda. While this strip is long it is so narrow that the total area probably does not exceed 9 square miles.

Besides these two pools there are several smaller ones found in different parts of the country. The positions and areas of these are made clear from the following descriptions:

Allen Township.—The producing territory extends south from Henry township, Wood county, into Allen of Hancock, entering section 2, and running nearly due south as a narrow strip about three-fourths of a mile in width, to near the south line of section 11. At this point the western boundary of this strip bends due west entering section 10 of Portage.

Continuing south in Allen township the producing territory covers a tract one and three-quarters miles in width including in whole or in part sections 13, 14, 23, 24, 25, 26, 35 and 36. Near the village Mortimer a very narrow belt leaves the main area, extending nearly due east about one-half mile, then making a right angle, and running due north one and one-half miles. This lies principally in sections 18 and 19. Gas wells are found in sections 6, 7, 12, 17, 18, 19, 30 and 31.

In the extreme northeast corner of this township a few acres of oil territory are found. This extends south from Bloom township, Wood county, and west from Cass of Hancock.

This was part of the earliest territory to be developed in this county. After the completion of the pioneer wells at Findlay work was extended northward, fine producers of gas having been secured in many cases. With the active beginning of the oil industry in 1886 work began in earnest in this township, and drilling has been in progress with little interruption since that time. The limits of the producing territory have long been demonstrated, and the later work has been within these.

Portage Township.—The producing territory of Henry township, Wood county, extending south enters section 4 of Portage township, Hancock county. It is there over one-half mile in width. From this point the area runs southeast through sections 4 and 10; near the line of junction of these, the strip is very narrow, being represented in fact by a few scattering wells only. From section 10 the eastern margin of the territory under consideration extends east into Allen township. The western margin of the pool extends south through sections 10, 15, 22, 27, 28 and 33, and then west through 33, 32 and 31.

This township lies west of Allen, and its development went hand in hand with that. Probably by 1890 the limits of the producing territory had been demonstrated. The greater part of the drilling has long been done, and the life of the field will be determined by that of the wells already drilled.

Liberty Township.—The territory in Portage and Allen townships extends south into Liberty township, and also into the corporation of Findlay. In the latter the margin of the pool runs nearly south to Sandusky street where it turns west passing from the city limits. Outside of Findlay the pool includes the whole or part of sections 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 14, 15, 16, 17, 18, 20, 21, 22, 23, 27, 28, 29, 32 and 33.

This has the largest area of producing territory of any township in the county. Active drilling for oil began in the spring of 1886, making the real beginning of the industry in the county. Wells have been drilled from time to time since that date. At first they were put down rapidly and in great numbers, but in a few years the best territory was drilled, and since that time work has been much quieter. From this township the pioneer drilling extended north into Allen and Portage.

Eagle Township.—About one mile southwest of the large pool in Liberty township there is a small pool in Eagle township. It has an area of perhaps two and one-half square miles, and includes parts of sections 5, 6, 7, 8, 17, 18 and 19. From this it runs west into Union township. Farther south along the township line a small pool is found in the north-west quarter of section 31.

Development in this township lagged behind that in the townships previously considered. Work is reported to have begun about 1891, and the small areas of production were soon outlined. However, the drill was still at work in 1902, and with fair success.

Union Township.—The oil territory in this township is restricted to the southeastern quarter. The main pool in Eagle township extends just over the line into Union, but the small pool in the southwest corner of Eagle expands after having entered Union, and includes parts of sections 23, 24, 25, 26, 35 and 36. From section 35 the pool extends south into Orange township. In the northeast quarter of section 27 a few wells are found.

The discovery and development of the productive territory in this county may be correlated with that in Eagle. Some wells were still being drilled in 1902, and it is probable that work will be continued on a small scale for several years.

Orange Township.—The pool in Union township to which reference has just been made extends into the north half of section 2, and then disappears.

The western half of this township contains an extension of the Allen county pool, including section 8, and parts of 4, 5, 6, 7, 9, 10, 15, 16, 17, 18, 19, 20, 21 and 29. Section 30 also contains a few wells, another extension from Allen county.

Cass Township.—The great pool in Bloom township, Wood county, extends south into Cass township of Hancock, entering in the extreme northwest corner, and extending south entirely across the township. It forms a narrow strip ranging in width from less than one-half mile to more than a mile, and includes parts of the following sections,—4, 9, 10, 14, 15, 16, 22, 23, 26, 27, 34 and 35. The township produces some gas from sections 4, 14, 15, 22 and 23.

Development began at an early day, probably in 1886, and work has been in progress since that time. However, the production has never been large, and not much can be expected in the future.

Marion Township.—The territory referred to above extends south entering Marion township in sections 2 and 3. From section 2 a branch runs due east entering Big Lick township, but the main strip runs slightly east of south, passing through sections 11, 12, 13, 14, 23, 24, 25 and the northeast corner of 36, and then bending east enters Big Lick. The

width of the territory in Marion township ranges from one-eighth mile to one mile or more. The township still yields considerable natural gas. The wells lie in sections 1, 2, 3, 6, 8, 11, 12, 14, 15, 16, 17, 21, 22 and 23.

As late at least as 1890 extensive gas territory existed in this township, but the rock pressure had become relatively small, and many wells began flowing oil. By 1892 the yield of oil had become large, and from that time the township may be classed as a producer of oil rather than of gas. Ten years later considerable drilling was still being done.

Big Lick Township.—The oil fields of Marion enter this township in the northwest and southwest corners. That in the northwest corner passes through sections 6, 7, 8 and 17.

That in the southwest corner enters sections 30 and 39 and taking a southeasterly course enters Amanda township. The producing territory in this township is very small. Its area is about one square mile. The development is reported to have begun in 1897.

Amanda Township.—The territory entering this township from Marion forms a very narrow strip, and does not reach the middle of the section. It comprises about 20 acres, and was drilled principally in 1900.

Jackson Township.—The principal production of this township is natural gas, the greater number of the wells being found in sections 15, 16, 21, 22, 27 and 28, but gas wells are found in sections 5, 6, 7, 8, 9 and 26 also. In the extreme southeast corner of the township a few small oil wells are found.

Delaware Township.—The small pool of oil just mentioned extends over the line into Delaware township where it comprises about 80 acres, located in section 2.

Wells Drilled.—The well record in Hancock county for 1891 to 1899 was as follows:

Year.	Producing.	Dry.	Total.
1891	115	25	140
1892	78	13	91
1893	76	4	80
1894	276	64	340
1895	409	84	493
1896	576	103	679
1897	359	73	432
1898	263	38	301
1899	439	58	497
Totals	2,591	462	3,053

This shows 84 per cent. producers and 16 per cent. dry.

GEOLOGY OF THE COUNTY.

The surface rocks in the western and northern parts of the county are the Lower Helderberg limestone, and in the eastern part the Niagara. The succession of strata under ground is shown by the following record of a well at Findlay.¹

	Feet.
Drift	8
Niagara limestone.....	162
Blue limestone.....	5
Niagara and Clinton limestone and shale.....	108
Medina shale, red.....	47
Cincinnati shales, blue with thin sheets of limestone..	462
Utica shales, brown.....	300
Trenton limestone at.....	1,092
Bottom of well (in Trenton).....	1,648

The position of the Trenton along an east-west line in the northern part of the county is shown by the following data:

Pleasant Township, near McComb: drive pipe, 62 feet; casing, 630 feet; Trenton at 1,412; elevation of well head, 730 feet above sea level.

Portage Township, northwest quarter of section 10: drive pipe, 34 feet; casing, 409 feet; Trenton at 1,201 feet; elevation of well head about 750 feet above sea level.

Allen Township, west of Van Buren: Trenton at 1,232 feet; elevation of well head, 780 feet above sea level.

Cass Township, southwest quarter of section 15: Trenton at 1,150 feet.

Washington Township, near Arcadia: Trenton at approximately 1,200 feet; elevation of well head, 806 feet above sea level.

These records indicate a gradual slope from the center of Cass township to the east and west. Just north of Van Buren, Allen township, the Trenton is found at 305 feet below sea level, this being probably its highest altitude in the northern part of Hancock county. Examination of the tier of townships lying south of that just given shows similar conditions. Wells drilled outside of the main pools show the same general succession of strata and depths as those previously given. In fact, the Trenton limestone in the producing portions of Hancock county lies nearly flat, the altitude varying but little from place to place. To this there is one noteworthy exception—the Findlay arch. This has already been fully described by Dr. Orton in Volume VI, and the First Annual Report (1890) and those who desire a detailed account must refer to those volumes.² Suffice it to state here that at Findlay a sharp bending of the strata is found, the result being that the Trenton drops to the west 150

¹*Geol. Sur. of Ohio*, Vol. VI, p. 112.

²*Ibid.*, pp. 120, 133-5 and First Ann. Rep. 1890, Plate II.

feet in less than one-half mile. It was at the margin of the higher side of this flexure that the great Karg well was drilled. East from Findlay the rock lies nearly horizontal, as has already been stated. Its depth, however, increases slowly on both the east and west sides of this arch.

Another interesting disturbance is found in section 22 of Cass township. This is a peculiar folding of the Trenton rock, called by drillers "the hog back." On the Hiram B. McCracken farm, in the northeast quarter of the section, the Trenton is found at 1,040 feet; on the A. M. Greenlee farm, a well 400 feet east of the last one found the Trenton at 1,167 feet, a drop of 127 feet; one-quarter of a mile west of the McCracken well the Trenton was found at 1,107 feet, a drop of 67 feet; and one-fourth of a mile south it was found at 1,115 feet, a drop of 75. Drillers report the formations in the "hog back" liable to cave, while the Trenton is said to contain many fissures. Salt-water is abundant.

The oil rock east of Findlay sometimes contains numerous holes, resembling in some respects a sponge, and drillers frequently report crevices in the formation, as is shown by the tools dropping suddenly from a few inches to several feet. West of Findlay the cavities in the Trenton are less common, but the oil is not confined to the surface portions of the formation. In fact, several "pays" are sometimes found, but these do not form well-marked bands or zones. In the southwestern townships the lower pays had not been worked prior to 1899; since that time many old wells have been drilled deeper, and in this manner changed from the nearly exhausted to good producers. The oil secured from the lower pays has thus far been insignificant in value in comparison with that received from the higher or first pay. The latter is commonly formed at a depth not exceeding 50 feet.

Production of Wells.—It is difficult at this late date to give accurate data concerning the initial production of individual wells. Doubtless, however, there were many which yielded hundreds of barrels per day, and perhaps occasionally one that flowed 1,000 barrels or more. At the present time, however, the wells are small. The territory in the eastern part of the county, having been developed more recently than that farther west, has the largest producers. On section 15 of Cass township the average production per well is about 5 barrels per day; on section 22 it is not less than 25 barrels. In Marion township the average production is smaller, having been reported at 20 barrels. The wells are kept pumping day and night to control the large volume of salt-water which threatens their life. The ratio of salt-water to oil pumped in 1902 was about five to one.

Amanda township makes a similar report for its small territory. On section 6 the wells averaged each about 15 barrels per day in the summer of 1902. In July, 1901, two wells completed on this section had an initial production of 8 barrels daily, but after having been shot the production

increased to 150 barrels per day for 20 days. By June, 1902, the production had diminished to 6 barrels per day.

West of Findlay the largest wells pump from 35 to 45 barrels per 24 hours, but those exceeding 15 barrels are rare, and many yield from two to three only. This territory was one of the first to have been developed, and this fact accounts for the present small production. It is interesting to note that some of the wells drilled 16 years ago (1886) are still producing.

In Eagle and Union townships the production averages less than five barrels per well each day, while in Orange township the yield is only about one-third of that. These wells produced from 50 to 60 barrels per day in 1896.

SANDUSKY COUNTY.

It was very natural that this county, lying as it does, just east of Wood and northeast of Hancock should be stimulated by the great discoveries made to the west and south. Fremont led the way, reaching the Trenton rock July 8, 1885, at a depth of 1,328, or 720 feet below tide. Considerable gas was liberated at several horizons, especially the Clinton, but there was little or no addition to the flow when the Trenton was reached, even after the latter had been torpedoed. However, the test demonstrated the existence of fuel, and that insured further exploration. By 1888 nine wells had been drilled in the vicinity, the results being similar to those disclosed by the first well. Small as the yield was, the company determined to make the most of it; accordingly a line was laid to the city, and a few citizens were soon enjoying the luxury of natural gas. The supply, however, was short lived. Finding gas in the Clinton formation and little or none in the Trenton, a number of shallow wells were drilled, the hope being that if the gas obtained from the Clinton should be small, it might be profitable, since the cost of drilling would also be light. However, the experiment was not a success, and the Northwestern Natural Gas Company was soon supplying the town from the great Wood county fields. Notwithstanding these repeated failures a well was drilled on the river bank near the State street bridge in 1901. The result was less encouraging than the tests made 15 years earlier, not a showing of either oil or gas having been found.

Later, tests were made to the west with better success, though not without disappointments. The records of these will be given later when the territory is taken up by townships. By inspection of the map it will be seen that the principal territory lies in the western tier of townships. A barren strip extending lengthwise through this territory is a feature.

Woodville Township.—A large part of this township produces oil, the sections being 8, 17, 18, 19, 20, 21, 22, 27, 28, 29, 30, 31, 32, 33, 34 and 35.

The first test was made at Woodville in 1886, the object being natural gas for use in burning lime. The Trenton was found at a depth of 1,184,

or 586 feet below tide level, being entirely free from the desired fuel and from oil also. So conclusive did the results seem that the well was not shot, which, as later developments proved, was a great mistake.

About two years later the search was renewed; this time with better results, though not so far as natural gas was concerned. Oil was found in paying quantities, and of course the drill was kept at work, the result being that what had at first been condemned as worthless territory proved to be rich in oil. Not only was the rock quite free from barren streaks, but several large wells were secured.

Madison Township.—This township, lying south of Woodville, has oil wells in every section excepting 15, 28 and 35, but in several others the areas are very small. The barren strip to which reference has already been made extends entirely across the township from north to south.

In 1887 a well was drilled at Gibsonburg for natural gas. The Trenton was struck at 1,237 feet, but flowed oil, the rate reported having been 50 barrels per day. This is said to have been the first oil well drilled in Sandusky county. Encouraged by this result another well was begun, the location being 2,000 feet west of the first one. This flowed gas, the rock pressure having been about 300 pounds per square inch. Other wells were completed with similar results, and the town was soon supplied with fuel. The flow of gas has been continuous, but is no longer adequate to meet demands (1902). The first well drilled in this locality exclusively for oil was in 1888. After having been shot with 80 quarts of nitro-glycerine, it began producing at the rate of 200 barrels per day. Progress has been uninterrupted since that early day, and consequently the territory is now well drilled.

Scott Township.—The oil territory of Madison township extends south into Scott, where all sections are productive, in whole or in part, except 2, 11, 12, 13, 14 and 24. From this township the production extends west into Wood and south into Seneca counties.

Development was contemporaneous with the township north, real progress beginning about 1890. Since that time the tools have been kept at work, the result being that little remains to be done.

Washington Township.—The territory in Woodville and Madison townships extends east into Washington, occupying in whole or in part sections 5, 6, 7, 8, 9, 16, 17, 18, 19, 20, 21, 29, 30, 31, 32 and 33. Outside of this three smaller pools are found; one lies at the junction of sections 23, 24, 25 and 26, the wells being about equally divided in production between gas and oil. About one-half mile north of this pool a gas well has been secured; the original rock pressure exceeded 400 pounds, the gas being used in carbon works at Fremont. In the southern part of the township a small pool of oil has been found occupying a fractional part of sections 34 and 35; it extends across the line into sections 2 and 3 of Jackson

township. Another small pool is found just southeast of Lindsey, in sections 11, 12 and 13.

Rice Township.—The little pool to which reference is made in the preceding paragraph extends eastward into sections 5, 6, 7, 8 and 18 of Rice township. This is sometimes called the Kingsway pool from the station of that name. Drilling began here about 1896 and has been continued since. As a rule the wells are small, and this has made development slow. The largest production reported was 70 barrels per day, and the normal about one-tenth of that. In July, 1902, the wells averaged about one and one-half barrels each per day.

Jackson Township.—A narrow strip of producing territory is found along the western border of this township. It includes in whole or in part sections 5, 6, 7, 8, 17, 18, 19, 20, 30, 31 and 32. Besides, there is a small area in sections 2 and 3, as has already been mentioned in the discussion of the preceding township. A number of gas wells are found in sections 31 and 32; these supply in part the villages of Burgoon and Kansas.

Wells Drilled.—The following figures show how extensively wells were sunk in the county from 1891 to 1899:

Year.	Producing.	Dry.	Total.
1891	198	35	233
1892	285	34	319
1893	389	39	428
1894	496	47	543
1895	924	70	994
1896	810	41	851
1897	239	19	258
1898	260	9	269
1899	431	21	452
Totals	4,032	315	4,347

GEOLOGY OF THE COUNTY.

The surface formation in the western part of the county, including the principal oil producing territory, is the Niagara limestone. Farther east the Lower Helderberg limestone extends across the county as a broad belt from north to south. This in turn is succeeded by a strip of Niagara, and this again by the Lower Helderberg; so that there are in all four separate belts of Niagara and Lower Helderberg limestones.

The underground succession is shown by the following record of a well at Fremont:¹

¹*Geol. Sur. of Ohio*, Vol. VI, p. 112.

	Feet.
Lower Helderberg limestone.....	160
Niagara limestone.....	200
Niagara shale, and Clinton limestone.....	105
Medina shale.....	105
Cincinnati (Hudson River) shale.....	450
Utica shale.....	308
Trenton limestone at.....	1,328

Next is given a record of a well near Rollersville, in the southern part of Madison township; the well head is 689 feet above tide level:

	Feet.
Drive pipe.....	30
Niagara Series	Gray limestone..... 140
	White limestone..... 160
	Blue limestone..... 20
	White slate (first break)..... 2
	Brown limestone (hard)..... 21
	Light slate (second break)..... 20
Clinton limestone	100
Medina shales, red, soft.....	80
Cincinnati (Hudson River) shales.....	427
Utica shales, brown.....	252½
Trenton limestone at.....	1,252½

From this it is seen that the Trenton rock lies about 563 feet below tide level; it dips very gently to the north, being found 586 feet below at Woodville seven miles distant; near Lindsay, in the northern part of Washington township, it is 650 feet, and at Fremont 720 feet. In other words, the Trenton rock lies highest in the southwestern corner of the township, sloping very gently to the north, and in the same manner to the east. In the latter direction, however, the rate soon changes, and as a result the depth of the Trenton is found to increase rapidly, as is shown by the Fremont well.

The Oil-rock.—This is in all cases the Trenton limestone. Its character agrees in every respect with that found in Wood and other counties. Formerly it was customary to drill a few feet only into the oil-rock; later, depths from 50 to 100 feet were reached, and this custom now prevails, especially with the largest producer in the field—The Ohio Oil Company. The greater depth has the advantage of penetrating a possible deeper pay, and also acting as a cistern into which the sediments may accumulate. All wells are torpedoed, the size of the charge ranging ordinarily from 50 to 200 quarts. The pay commonly ranges in thickness from 5 to 30 feet; it is more porous and commonly has a darker color than the enclosing rocks, and hence is easily recognized.

Barren Area.—As has already been stated there is one conspicuous barren area; this has a length of ten miles and a width usually of from

two to three. Occasionally a small group of wells is found in this area, but their production is small and life short. Mr. F. W. Zorn, of Gibsonburg, who has had much experience in the territory under consideration, states that a small syncline runs through the barren tract northwest and southeast, that is, parallel to the longer axis. He reports also the rock hard and fine. It appears to the writer that the barrenness of the rock is due more to the latter qualities than to the syncline, since the depression is very inconspicuous. The existence of small wells lends support to this theory.

Size and Duration of the Wells.—By far the greater number of wells have been of ordinary size, that is the initial production has ranged from 25 to 100 barrels per day. There have been a few notable exceptions to this, one of which is famous in the history of the oil fields in northwestern Ohio.

The first of the large wells was not drilled until August, 1892. It was located on the Baker farm in section 29, Woodville township, and had an initial production of 200 barrels of oil per hour, and 2,500 per day.¹ Some have placed the production considerably higher.

The great well to which reference has already been made is known as the Kirkbride. It stands on the H. Jones farm in the southeast corner of section 19, Madison township, and was completed November 17, 1894. A short time before, a well was drilled on the Myers farm adjoining, and after having been shot is reported to have produced 2,000 barrels of oil the first day. Good wells were secured north of this one, so that the territory was in good repute before the Kirkbride was drilled.

Work progressed in normal fashion for the district. When the Trenton had been penetrated to a depth of about ten feet a great pool of oil was liberated. The oil was thrown as a solid stream to the top of the derrick where it was broken by the crown pulley, and the spray caught by a strong south wind was carried a mile north. A half-mile from the well, farmers were obliged to disconnect the spouting on their houses to prevent the oil from running into the cisterns.

The oil began flowing about 9 in the morning; and the drillers, not expecting a heavy production, were totally unprepared. Not until the middle of the afternoon was the giant gotten under control, and during all this time the oil was thrown over the derrick and then fell on the ground below. Part of this, however, was saved by damming a stream into which the oil flowed. When under control the well was never allowed to flow freely, and so its maximum production was never determined. This, however, has been estimated all the way from 10,000 to 40,000 barrels the first day. While wells of comparatively small size are usually greatly overestimated, the writer believes that those of the Kirkbride type are commonly underestimated. In January, 1901, the well was pumping four

¹*The Derrick Hand Book of Petroleum*, Vol. I, p. 550.

barrels per day. It was still producing in August, 1902. The fact that just across the road from the Kirkbride very small wells were secured has given rise to the belief that the great well was of the crevice type.

The life of the wells corresponds to that found in adjacent counties. Those in the so-called barren tract, as has already been stated, are soon abandoned; but those in better territory produce much longer. In fact, it is doubtful if the maximum life of a well in this county has yet been determined. The oil ranges from 38 to 39 deg. B. in gravity.

Salt-water.—This has been found in all parts of the county, but the quantity has been smaller than in Wood. Nowhere does the brine seem to have been a serious obstacle. Sometimes a small quantity has been found in the Clinton, but here as elsewhere the great volume has come from the Trenton.

SENECA COUNTY.

Lying east of Hancock county, and containing the two progressive cities Tiffin and Fostoria, it was very natural that the underlying rocks of Seneca county should be tested early. The results of these explorations have already been outlined: Fostoria never secured the desired gas, though she later obtained a supply from Wood county; and oil too was denied her. Tiffin was a little more fortunate, securing a small quantity of both products.

Developments during the past fifteen or sixteen years have done very little for the county, though the rocks have been extensively tested. The only productive territory is found in the northwestern corner, and around Tiffin.

Hopewell and Clinton Townships.—This includes the Tiffin pool, having a length of four miles and a width not exceeding one and one-half miles. By far the greater portion of the territory lies in Clinton township, a strip a few hundred yards wide only extending into Hopewell.

The first well was completed in January, 1886, and made a showing of oil, gas and salt-water. After having been shot with rack-rock it was put to pumping; and yielded a small quantity of oil for several years. Well No. 2 drilled the same year, was located about one mile west of No. 1, and found the Trenton rock 120 feet lower than the latter well. After having been shot this well flowed from 8 to 15 barrels of oil per day; it continued flowing until 1900 when it was put to pumping; in July, 1902, it was still numbered among the producers. These results gave rise to much excitement, and led to extensive leasing of land in the vicinity of Tiffin. Several additional wells were drilled in 1887, but the results did not meet early expectations, and matters became quiet until 1892.

During that year a large number—perhaps two score of wells were drilled along the banks of the Sandusky river, many of them in the heart

of the city. The wells are said to have all been producers, the initial production ranging from 30 to 120 barrels per day.

In 1895 the Beatty Glass Company drilled a well for gas on the Maul farm along the corporation limits. The well was shot, and then, instead of yielding natural gas, flowed 100 barrels of oil per day. The well is reported to have been sold for \$8,000.

The next and last boom started in 1900. In that year a well was drilled on the Van Natta farm, by the side of a gas well drilled eight years before. The new well made the largest demonstration of any drilled in the vicinity of Tiffin. It flowed two or three times per day, and each flow is reported to have produced from 300 to 400 barrels. Once more Tiffin had the attention of the driller; work soon began in earnest, and before the boom was over about 50 wells had been drilled in the vicinity of the Van Natta. A goodly number of these were dry, but about 20 of the producers were still yielding oil in July, 1902. An effort was made to extend the territory to the southeast, and while oil was found in nearly every well, the quantity was not such as to warrant operation.

Since 1900 the territory has been quiet, only an occasional well having been drilled.

Jackson Township.—This contains a larger area of oil territory than any other township in the county, comprising sections 4, 5, 6, 7, 8 and parts of 1, 2, 6, 9, 10, 15, 16, 17 and 18. The territory is an extension of that in Sandusky county on the north and Hancock county on the west, and its development followed naturally that of the adjacent counties.

Liberty Township.—This contains no oil territory, but in the north-western corner, near Kansas, there is a small reservoir of gas. The first well was drilled about 1895 and the flow has been continuous since that time. However, the village is connected with several wells just over the line in Sandusky county, and these have done half or more towards keeping up the supply. About 60 fires are supplied, the rate being \$3.00 each in winter and \$1.50 in summer. The gas is found at about 35 feet in the rock, and at a depth of about 50 feet work ceases.

Wells Drilled.—The wells drilled in this county from 1896 to 1899 have been as follows:

Year.	Producing.	Dry.	Total.
1896	228	10	238
1897	47	6	53
1898	66	1	67
1899	53	2	55
Totals	394	19	413

This shows that 95 per cent. of the wells drilled were producers.

GEOLOGY OF THE COUNTY.

The surface rocks in the western part of the county belong to the Niagara; those near the middle to the Lower Helderberg; and those farther east to the Corniferous limestone and the Ohio shales. By far the greater part of the producing territory has the Niagara for the surface formation. The topography resembles that of the adjacent counties on the west; it is flat on the west and northwest sides, rolling in the middle and eastern parts. A beach of ancient Lake Erie crosses the county from the southwest to the northeast, and is the most striking feature of the surface geology of the county.

The succession of strata underground corresponds very closely with that in the counties west and north, and consequently will not be repeated here. The Trenton limestone in the northwestern corner of the county is part of the nearly flat dome, that forms so striking a feature of the oil territory in that part of the state. Its position is about 475 feet below tide level. From this corner the rock dips east and south, at Tiffin being 765 feet, and at Attica, on the east side of the county, about 1,130 feet below sea level. At Tiffin a small fold is found; well No. 1 drilled near the north of Rock creek, found the Trenton at 1,490 feet, while No. 2 drilled about one mile to the west, did not reach that formation until a depth of 1,610 feet was reached. The latter well stands on higher ground, but not sufficient to account for the increased depth of the Trenton. The boundaries and direction of extent of the arch have not been determined, but the productive territory indicates that it is crescent shaped, with the convex side turned to the west. In other respects the geology of the county is similar to that of Sandusky and Hancock, and the facts that have been stated for those counties will not be restated here.

ALLEN COUNTY.

The oil territory in Hancock county extends southwest into Allen, where it makes its first appearance in Richland township. It continues southwest across the county as a series of disconnected but closely related pools, and then enters Auglaize county. In the western part of Allen two large pools are found, and one of these extends westward into Van Wert county. Besides these pools there are several small ones. These points will be made clear in the following discussion by townships:

Ottawa Township.—This is coextensive with the Lima city limits. The first well was drilled in 1885, and work became active one year later. By April 1, 1886, fourteen wells had been completed; by July 1, fifty-seven, and by November 1, one hundred and sixty-five. The production by months was as follows:

	Barrels.
September (1886).....	4,500
October	7,000
November	8,300
December	9,500
January (1887).....	8,500
February	11,700
March	10,400

Doubtless, however, many of these wells were outside of Ottawa township. By April 1, 1887, there were 283 wells completed in the Lima field.

So impressed was Dr. Orton with the possibilities of the territory that he wrote in 1888: "The field has risen in importance until, at the present time, it is unquestionably not only the most important oil field that Ohio has ever had, but by all odds the most important field, so far as the possibilities of production are concerned, yet found on the American continent."¹

In 1902 the eastern part of Ottawa township was still producing oil, and not improbably good wells might be secured in the heart of Lima.

Richland Township.—The producing territory in Hancock county enters this township through sections 13 and 24, and continues southwest into 23 and 25, the maximum width being about one and one-half miles. In the western half of section 23 a small pool was opened in the summer of 1902, comprising at that time about 80 acres. In the southwest corner of this township a larger pool is found. This includes the territory around Beaver Dam, and hence is sometimes called the Beaver Dam pool. It includes parts of sections 27, 28, 29, 30, 31, 32, 33 and 34. A small outlier is found north of this pool. It seems very probable from work done in 1902 that all these pools will soon be connected.

Work in this township began late in 1885 or early in 1886, the test having been made at Beaver Dam. The Trenton was found at 1,309 feet and contained both oil and salt-water; but the former was small in quantity and the well was plugged and abandoned without having been shot. It remained in that condition until 1899, when new casing was inserted and the well put to pumping. At first it yielded 25 barrels per day, but this decreased rapidly and was very small in 1902. Encouraged by this experiment, other wells were drilled the same year. The first one was located within the corporation, and had a reported initial production of 100 barrels per day. Since that time work has been active, and, of course, the producing area extended. In 1902 fine wells were being secured in section 34, two and one-half miles east of Beaver Dam.

Jackson Township.—The Beaver Dam pool extends south into this township, entering the extreme northwest corner and including the whole or parts of sections 5, 6, 7, 16, 17, 18, 19, 20 and 30. The length exceeds

¹*Geol. Sur. of Ohio*, Vol. VI, p. 168.

four miles, and the maximum width approaches two and one-half miles. About one mile east of this pool a small outlier is found in sections 15 and 22. Near the village of Lafayette a number of wells have been drilled, but without favorable results. It seems quite probable in view of recent developments near the south line of Richland township that section 13 of Jackson may also soon be included in the producing belt.

Monroe Township.—This lies west of Richland, and has an extension of the Beaver Dam pool in the southeast corner. This includes parts of sections 25, 26, 35 and 36, though it comprises one square mile only. A number of wells have been drilled in other parts of the township, but without success. The sections on which tests have been made are 13, 16, 17, 18, 20, 21, 31 and 33. It is one of the parts of the county most recently developed. From tests made it does not seem probable that the township will become an important producer. However, if in the future smaller wells can be operated with more profit than at present, this territory may be more extensively drilled.

Bath Township.—In the extreme northeast corner of this township a small extension of the Beaver Dam pool is found. This comprises about one-quarter of a section. Near the center of the township a small pool, about one-half section in area, is found. It includes parts of sections 9, 10, 15 and 16. A large extension of the Lima pool is found in the southern half of the township. It includes sections 26, 27, 28, 29, 33, 34, 35 and parts of 19, 20, 21, 22, 23, 24, 25 and 36.

The development of this township began at an early day, perhaps late in 1885, and the drill has been kept at work ever since. Little progress has been made in late years, however, and no important extensions need be expected.

Perry Township.—The larger portion of the township is occupied by what has already been referred to as the Lima field. It includes sections 2, 3, 4, 7, 8, 9, 16, 17, 18, 19, 20, 21 and parts of sections 1, 10, 11, 12, 14, 15, 22, 23, 28, 29 and 30. This township contains a portion of the territory that was the first to be developed in northwestern Ohio. Work began in 1885 and drilling is still being done. Territory that was once discarded as worthless has been proven to be quite valuable.

Auglaize Township.—This occupies the southeastern corner of the county. The only producing territory is in section 6, where a small extension of the Lima field is found. However, tests have been made at several places, including the following sections,—5, 8, 10, 17, 18, 21 and 25.

Shawnee Township.—This includes part of the Lima pool, the sections being in whole or in part 13, 19, 20, 21, 23, 24, 25, 26, 27, 28, 29 and 30. Besides this there are five small pools in the township; one of these containing two or three wells, lies in the middle of section 28, and another of similar size is found in the northeast quarter of section 6. In sections 5

and 8 there is a pool having a length exceeding one mile, and a width less than one-half mile. Another small pool runs northeast and southwest through sections 1, 11 and 12. The length of this approximates two miles, and the width one-half mile. The largest of these outlying pools extends nearly north and south through sections 3, 9, 10, 15, 16, 21 and 22. Its area, however, does not exceed two square miles.

German Township.—Two pools are found in this township, a small one lying near the eastern line and including the larger part of section 13 and parts of 14 and 24; the second and larger pool lies principally in the northwestern corner of the township. It has a length of four and one-half miles, a maximum width of one and one-half miles, and includes parts of sections 7, 8, 9, 10, 11, 15, 16, 17 and 18. Enclosing as it does the village of Elida, this territory will be called the Elida pool.

Tests were first made in the vicinity of the village just named at an early day, probably in 1886. However, the object was natural gas, and when instead of this a small quantity of oil was found the wells were abandoned. Not until about 1895 was work resumed, when a 40-barrel well was secured. Since that year drilling has been in progress, and bids fair to continue for some time.

Marion Township.—From German township the Elida pool extends due west into Marion, where it includes parts of sections 2, 3, 10, 11, 12, 13 and 14. Considerable drilling was being done in the southeastern part of this township in 1902, and it is probable that the areas as above outlined are not now complete.

In the southwest corner of the township in sections 11, 12 and 7 and 8 an extension of the Spencerville pool is found.

Much of the work done in this township has been recent, and not improbably considerable drilling remains to be done.

Amanda Township.—In the northeastern corner of this township a small extension of the Elida pool is found. It includes parts of sections 23, 24 and 26. The southeastern corner of the township contains an extension of the producing territory in Auglaize county. Parts of sections 11, 12, 13 and 14 are included in this. Another small extension from Auglaize county is found in the southwestern corner of section 16. A small pool is found in the northern part of the township in section 21. Along the west side of the township is found a part of the Spencerville pool. It includes parts of sections 7, 8, 6, 31 and 30. Outside of these pools many wells have been drilled, so that it does not seem probable that important extensions will be made.

Spencer Township.—This contains 21 square miles, at least one-half of which is productive. The territory includes the whole or parts of sections 10, 11, 12, 1, 2, 3, 4, 35, 36, 25, 26, 22, 23, 24, 13, 14 and 15. The northern half of the town of Spencerville lies within this belt, and for that

reason the pool is called the Spencerville. On the east it extends into Amanda township, on the north into Marion, and on the west into Van Wert county.

About the year 1886 a well was drilled near the town of Spencerville. The result was a good flow of gas, which was piped to the town. In 1902 the town's reliance was on five wells, three of which were on the southeast quarter of section 26 and two on the southwest quarter of section 8, Amanda township. All produced some oil with the gas. The Trenton in these lies 6-7 feet higher than that in the adjacent oil wells. The supply originally was derived from wells lying south and southeast of town. Later the fuel was piped from Auglaize county. In 1902 the company supplied about 100 houses, charging 25 cents net per thousand cubic feet.

Oil was discovered in the vicinity of Spencerville almost as soon as gas, and drilling has been in progress irregularly since that time. Whenever a good well located outside of the producing territory was drilled, other wells were at once begun, and in this way a small boom developed. Periods of activity were reported in 1886, 1895, 1899 and 1902.

Very little work is now being done. Many wells have already been abandoned, and others are so small that they hardly pay for pumping. The township has long passed its zenith, and the production is slowly but surely declining.

Wells Drilled.—The following table shows the number of wells drilled in the county from 1891 to 1899:

Year.	Producers.	Dry.	Total.
1891	85	11	96
1892	35	3	38
1893	16	4	20
1894	50	13	63
1895	168	47	215
1896	174	52	226
1897	169	43	212
1898	226	43	269
1899	689	96	785
Totals	1,612	312	1,924

This shows 83 per cent producers and 17 per cent failures.

GEOLOGY OF THE COUNTY.

The surface of Allen county presents considerable variation. The western and northwestern parts are flat; the northeastern gently undulating; and the southern rather hilly, owing to the presence of a well-developed moraine.

The succession of strata underground at Lima is shown by the following record:

	Feet.
Drift	7
Lower Helderberg, Niagara and Clinton limestones..	333
Clinton shale.....	40
Medina shale.....	50
Cincinnati (Hudson River) shale.....	470
Utica shale.....	350
Trenton at.....	1,250
Gas at.....	1,256
Oil at.....	1,260
Salt water at.....	1,272

Next is given a record of the Shull well, the pioneer at Beaver Dam, in the northeastern corner of the county. The well head was 860 feet above tide:

	Feet.
Drift	33
Lower Helderberg and Niagara limestones.....	247
Clinton limestone.....	40
Clinton shales.....	105
Medina shales.....	50
(475 feet of casing.)	
Cincinnati (Hudson River) shales.....	580
Utica shales.....	273
Trenton at.....	1,303
Bottom of well.....	1,345

Finally there is given a generalized section in the Spencerville pool, lying along the west line of the county:

	Feet.
Drift	5- 50
Limestones	300- 325
(Casing 360-380 feet)	
Shales	800- 850
Trenton at from.....	1,170-1,227

These and other records of a like nature show that the Trenton rock in Allen county lies highest in the southwestern corner. At Spencerville the formation is 328 feet below sea level; at Delphos, about 9 miles due north, it has dropped to 453 feet, about 14 feet to the mile. At Lima the Trenton lies about 390 feet below sea level, but at Elida, 6 miles to the northwest, the rock is 34 feet lower. At Beaver Dam, in the northeast corner of the county, the rock lies 443 feet below tide level, while due east of Lima, along the western line of Hardin county, the Trenton is found at about 470 feet below sea level.

It appears that a low fold extends across the county, running from Spencerville due east to Lima; thence northeast to Beaver Dam, and continuing in that general direction enters Hancock county. The fold is nowhere sharp; in fact, following from well to well gives the impression that the rock lies practically flat.

Around Beaver Dam it has been the custom to drill from 50 to 100 feet in the Trenton, but the oil and gas are usually found at depths not exceeding 35 feet. It is a general rule that the top of the rock in question is free from the desired products. The territory in this part of the county is quite spotted, due apparently to changes in the texture of the rock. The wells are shot with from 120 to 240 quarts of nitro-glycerine. Casing is inserted when the shales above the Clinton limestone are reached; in the language of the driller, the casing extends into the second break.

In the vicinity of Lima the drift is quite spotted, and sometimes very deep. The suddenness of the changes in depth shows that the underlying limestones have been deeply notched before the drift was deposited. This work was done by running water, and these unusual depths of drift are in preglacial valleys or gorges. One of these apparently starts a mile east of Lima, and extending southwest enters Auglaize county near Criddersville. The other heads near Elida and running slightly east of south unites with the first one near the county line. The greatest depth of drift reported in any of these old valleys is 394 feet, while outside of the valley the depth is usually less than 100 feet, and commonly does not exceed one-half of that.

What has been said with reference to the territory around Beaver Dam applies equally well to other parts of the county, for the geological relations are decidedly monotonous. Practically everywhere in the county some salt-water is pumped with the oil, but the quantity varies from place to place. Occasionally it is necessary to keep the pumps working day and night to keep the salt-water under control, a condition most common in the territory recently developed.

Production of the Wells.—Large wells have been secured in this county, but the greatest have not equaled those found in Wood. The first large well was drilled near Lima in the fall of 1887, and produced nearly 1,000 barrels of oil the first 24 hours. Six months later, when it had yielded 60,000 barrels, the production was still 150 barrels per day. A little later a well was drilled on the Ridenour farm in section 18 of Perry township which produced 2,760 barrels of oil during the first 24 hours.¹ This is the largest initial production in the county of which the writer has learned. In the northeastern part of the county the best wells started at about 500 barrels, but the number of these was small. On the west side of the county the best well reported yielded 600 barrels the first 24 hours.¹ No figure can be given for the average production, but it seems

¹*Geol. Sur. of Ohio*, Vol. VI, p. 178-9.

safe to say that by far the greater number produced from 25 to 100 barrels during the first day. The staying qualities of the wells have varied considerably in different places. Around Spencerville one well at least drilled in 1887 was still producing in 1902. At other points the decrease has been so rapid that the wells have hardly been profitable. An example of this sort is found in the pool in the southeastern part of Amanda township.

All parts of the county have now been tested, and it seems safe to predict that no large production of oil or gas will be discovered, though a trace of either or both may be found almost anywhere that a well is drilled.

AUGLAIZE COUNTY.

Oil territory in this county is very scattered. A few large pools are found, and many small ones. The great Lima field extends into the northern part, and the productive territory continues interruptedly southwest across the county, passing into Mercer on the west and Shelby on the south. Nine townships are included in this belt.

Duchouquet Township.—The Lima pool extends into the northern part of this township, and includes the whole or the part of sections 31, 32, 33, 34, 35, 36, 2, 4, 5, 6, 7, 8 and 17. The tier of sections along the county line is occupied quite largely by productive territory, but other sections have simply a narrow arm passing through them.

Drilling in this township was begun in 1885, the object being natural gas; but in this, as in so many other places, the effort was unsuccessful. Oil was discovered by attempting to extend the Lima field into Auglaize county. Much of the territory is now very old, the wells averaging from one to two barrels per day. New wells start at from five to fifteen barrels. Strong efforts have been made to extend the pool, but unsuccessfully. It seems safe to say that this township has passed its zenith, and that many of the wells will soon be abandoned.

Logan Township.—The oil territory in this township is very spotted. In the northeastern corner an extension of the Allen county field occupies parts of sections 23, 24, 25 and 36. In the northwestern corner a small pool, having a length of one mile and a width of a small fraction of that, occupies parts of sections 19 and 20. The principal territory, however, is in the central and southern parts of the township, comprising parts of sections 26, 27, 28, 29, 31, 32, 33, 34, 2, 3, 5, 6, 7, 8, 10, 11 and 12. Examination of the map will show at a glance the exceedingly irregular nature of the territory. The barren strips that are partially surrounded by productive areas are to be classed with similar ones in Wood and Sandusky counties.

The territory began to be developed in 1888, the first well having been drilled on the Gochenour farm in section 11. It started at 250 barrels, and other wells drilled in the same neighborhood gave equal or still better results. Two wells located on section 15 started at 600 barrels.

These results, however, were **unusual**, the greater number by far starting at less than 100 barrels.

The size and shape of this territory has changed considerably in the past three years; this has resulted principally from abandoning many small wells, but at several points new ones have been drilled, thus producing extensions at these places.

Moulton Township.—This lies south of Logan, and contains an extension of the territory in that township; besides this several smaller and independent pools are found. The producing sections include parts of 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19, 20, 21, 22, 23, 24, 26, 28, 29, 35 and 36.

However, the total area yielding oil is very small in comparison with its wide distribution. The development and history of the township are similar to Logan, and consequently will not be related here.

Washington Township.—In the northwestern corner of this a small pool is found extending from Moulton township into sections 1, 2 and 3. Another long narrow strip is found on the western side in 7, 8 and 9, from which it extends into Noble township. A few wells are found on the western side of section 6 also. These wells are small, and the production of little importance.

Salem Township.—The only producing territory in this township is along its borders, where extensions are found from adjacent townships. In the extreme northwestern corner a few wells are found; and the same is true in sections 6 and 31 on the west side, and 1, 4 and 5 on the south side. The entire production in this territory does not exceed one square mile.

Noble Township.—The oil territory extends northwest and southeast entirely across the township. Throughout a considerable portion of this belt the width is two miles or more. From this several narrow tongues branch to the east and west. In the southwestern corner of the township production is found in section 31 and to a small extent in 30 and 32. The territory in this township extends south into St. Marys, north into Salem and west into Mercer county.

Besides the sections named the producing belt includes parts of 7, 8, 9, 11, 12, 16, 17, 18, 19, 20, 21, 22, 23, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34 and 35.

This township comprises the larger part of the St. Marys oil field. Development began in 1888 and proceeded rapidly. In 1893 work was resumed with renewed vigor, and since 1900 has again been quite active. Numerous efforts have recently been made to extend the territory, but in the main these test wells have been failures. Many of the earlier wells have been abandoned, and the remaining ones are nearly all small.

St. Marys Township.—The two pools, previously mentioned as extending from Noble into St. Marys township, cross the latter as two narrow belts and then enter Washington, where they disappear entirely. The

northern one includes parts of sections 1, 2 and 3; the southern one parts of 6, 5, 4, 8, 9, 16, 10, 15, 11, 14, 12 and 13. The western end of this includes part of the Grand reservoir. Another pool is found in the southwestern corner of the township. It extends from the southeast corner of the reservoir nearly to the German township line, including parts of sections 19, 20, 28, 29, 33 and 34. Its maximum width is less than one mile. A few wells are found near the middle of section 32.

Work in this township began in 1886, the search being for gas. Both oil and gas were found in the pioneer well, but neither in large quantities. Later wells gave more favorable results, and for some months natural gas was the feature of the township. However, it was soon found that the real wealth lay in oil and not in gas. By 1890 the productive territory had been pushed to the eastern border of the Grand reservoir, and a year later wells were being drilled in that body of water. Those near the reservoir are reported to have been large—one or two with an initial daily production of 1,000 barrels or more. Those within the reservoir were smaller, owing probably to the adjacent wells having partly drained the underlying oil-rock. Many of these wells have already been abandoned.

The pool in the southwestern corner of the township dates back to the days of testing for gas. Fine oil wells were secured; the initial production of many ranging from 100 to 200 barrels, and the settled production from 25 to 50. In recent years the best of the wells drilled did not start at more than 25 barrels, and in 1902 the average daily production of the wells in the pool did not exceed one barrel.

German Township.—The oil territory here is very small; a few wells are found in section 4 in the northern part of the township, and in the southeast corner a narrow strip extends across section 13, running into Van Buren township (Shelby county) on the one hand and into Jackson township on the other. A few wells are found in section 13 also. Probably the entire productive area in the township does not exceed one-half of a section.

Jackson Township.—The narrow strip referred to above as passing into this township extends southwest, passing through sections 13, 14, 23, 22, 21, 28, 29 and 30. In the northwest corner of section 20 a small pool is found. This extends westward into section 19 and northward across the township line into section 17 of German.

While a few wells were drilled in both German and Jackson townships as early as 1887, the real work did not begin until 1896. Since that time much work has been done, and there seems little hope for the future, unless conditions are such that much smaller wells can be drilled with profit than at the present time. The wells are now rapidly approaching exhaustion, a large number having already been abandoned.

Wells Drilled.—The well record of Auglaize county for nine years was as follows:

Year.	Producers.	Dry.	Total.
1891	362	14	376
1892	157	19	176
1893	184	30	214
1894	298	50	348
1895	414	68	482
1896	246	62	308
1897	244	59	303
1898	195	44	239
1899	204	72	276
Totals	2,304	418	2,722

It is seen from this that 84 per cent. were producers and 16 per cent. dry.

GEOLOGY OF THE COUNTY.

The Niagara limestone forms the surface rock of the southern, north-eastern and northwestern corners; the Lower Helderberg limestone of the north central part of the county. The topography is flat or gently rolling, except where the moraine is found. This extends from near the Grand reservoir northeast past Wapakoneta, and is the most striking topographic feature of the county.

No complete log of a well has been secured; the following is from near St. Marys:¹

	Feet.
Drift	110
Niagara limestone	175
Niagara, Clinton, Cincinnati (Hudson River) and Utica shales	877
Trenton limestone at.....	1,162

At St. Marys the Trenton lies 313 feet below tide; at Minster about 260 feet, showing a fairly rapid ascent to the south. At Wapakoneta, in the central part of the county, the same rock is found at 348 feet below tide, and at Cridersville, in the northeastern corner, at about 360 feet.

Oil is found near the top of the rock only, all efforts thus far to locate a deeper pay having failed. The gas is small in quantity and is found with the oil. Salt-water causes little trouble. It lies deeper usually than the oil, so that the operator does not have to pump the brine, as he does when oil and water occupy the same rock.

A conspicuous feature of the county is a number of deep channels cut several hundred feet into the underlying rock. These undoubtedly

¹*Geol. Sur. of Ohio*, Vol. VI, p. 255.

represent the course of a river in pre-glacial times. The channel is filled with drift, and consequently wells in it require great lengths of drive pipe. One branch runs southwest from near Lima, past Cridersville, just west of Wapakoneta, to near the Shelby county line, where it unites with a channel that has been traced from near St. Paris, Champaign county, northwest past Anna into Auglaize county. The united channels run nearly due west from that point, passing through the Grand reservoir. Another channel is found in the southwest corner of the county, entering from Shelby on the south and extending into Mercer on the west.¹

Nothing additional to what has already been stated needs be said of the size and production of the wells. It is apparent that the largest did not rival the giants found farther north. However, the average production was good, and the territory must be rated among the important in north-western Ohio.

MERCER COUNTY.

Oil-producing territory in this county is badly scattered. Quite a number of pools are found, but the greater number of them are small. The territory enters the county from Auglaize on the east, and extends into Adams county, Indiana, on the west.

Union Township.—This lies in the northeast corner of the county, and has the largest area of producing territory. The latter enters the county from Van Wert on the north and Auglaize on the east. The producing territory includes parts of sections 1, 2, 3, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 21, 22, 23, 24, 26, 27, 28, 34, 35 and 36.

Successful wells began to be drilled in the township early in 1893, and during the two ensuing years rapid progress was made. A well is still drilled occasionally, but the life of the field will be determined by that of the wells already completed.

Center Township.—One small pool lies within the township, including a small part of sections 3 and 4. Besides this there are several small areas along the eastern line, extensions from Union on the north and Auglaize county on the east. The sections included are parts of 1, 2, 12, 24 and 25. The history and development in this township has been similar to that in adjacent ones.

Jefferson Township.—The producing territory includes two small pools entirely within the township, and part of a third which extends into Center on the north and Auglaize county on the east. The sections included are parts of 1, 2, 4, 5, 11, 12, 32, 33 and 36.

Drilling in this township began in 1886, the first well having been sunk at Celina. It made a show only of oil and gas, but those interested did not feel satisfied and accordingly a second well was begun. This was

¹For a detailed report of these channels, see Special Paper No. 3, Ohio State Academy of Science.

²*Geol. Sur. of Ohio*, Vol. VI, p. 259.

a complete failure.² Not until 1890 was oil secured in the township, and drilling has been done from time to time since that date. The largest of the earliest wells started at 250 barrels per 24 hours, but of course the average was much less. In the summer of 1902 the wells of the township averaged about one barrel only each per day, and many were being abandoned. The principal work during the year just mentioned was southwest of Celina. One well there started at 500 barrels per day, but a month later was yielding salt-water only.

Franklin Township.—The area in this is about the same as in Jefferson. However, by far the largest part lies almost entirely in the Grand reservoir. This pool has a length of about four miles and a maximum width of nearly one mile. Two additional pools, both very small, are found; one lies in the western half of section 23, and the other near the western line of 24. The area of the two combined does not exceed 40 acres.

Gas was discovered in the township late in 1886 or early in 1887 in section 24, near the Auglaize county line. Oil wells began to be drilled in 1890, possibly a little earlier. Progress was rather slow, owing to the difficulty of drilling in the reservoir. The township has been thoroughly tested, and it is probable that the production of oil will soon be a thing of the past.

Dublin Township.—The producing territory here does not exceed one-quarter of a section. It consists of three independent pools; one in section 5, another along the St. Marys river in the Black Loon reserve, and a third in the northwest corner of the township.

Black Creek Township.—This contains a narrow strip along the state line. It has a length of three miles and a maximum width of one and one-half miles. The included sections are parts of 18, 19, 30, 31 and 32. From this township it extends into Indiana.

Wells Drilled.—The wells drilled in the county from 1894 to 1899 were as follows:¹

Year.	Productive.	Dry.	Total.
1894	190	57	247
1895	218	43	261
1897	86	32	118
1898	80	10	90
1899	113	16	129
Total	687	158	845

This shows 81 per cent. producers and 17 per cent. failures.

GEOLOGY OF THE COUNTY.

Surface Features.—The surface formation of the county, with the exception of a small area in the northwest corner of Union township, where the Lower Helderberg is found, belongs to the Niagara. The topog-

¹No data for year 1896.

raphy varies from flat to sharply rolling, the latter a product of glacial action. Two moraines cross the county from east to west; one of these lies in the southern part, the other near the middle. The latter seems to be the more conspicuous. Two principal streams, the St. Marys river and the headwaters of the Wabash, cross the county. These and their branches have broken the erstwhile flat portions of the county.

Underground Features.—The succession and thickness of strata below drainage are shown in the following record of a well drilled at Celina:¹

	Feet.
Drift	70
Niagara limestone.....	{ Yellow 20 ft. White 65 ft. Drab 9 ft. Various shades 41 ft. }
Niagara shales	15
Clinton limestone	43
Medina shales	20
Cincinnati (Hudson River) shales.....	480
Utica shales	310
Trenton limestone at.....	1,110
Bottom of well at.....	1,168

This makes the Trenton 235 feet below tide; near St. Henry, in the southern part of the county, the same formation is found at 205 feet (approximately) below tide. Examination of a large number of wells in various parts of the county shows the Trenton lying at about 1,090 to 1,200 feet. The changes are gradual, indicating the absence of an arch, at any rate of a conspicuous one.

Thus far the deeper pays reported in Wood and adjacent counties have not been reported in the county under consideration. The oil is commonly found at depths in the Trenton not exceeding 25 feet. The rock is hard and fine, so that the wells usually make little promise until after having been shot.

One of the striking geological features of the county is the pre-glacial channel already mentioned in connection with Auglaize and Shelby counties. It enters Mercer by two branches; one from the east runs west through the reservoir, the other from the southeast extends northwest through Franklin township. The two unite in the reservoir a short distance east of Celina, and extend northwest past Rockford and then slightly south of west into Indiana, where it has been traced through Adams, Jay, Blackford and into Grant county. This old channel has been the most serious obstacle that the driller has had to contend with in those counties.

Size and Duration of the Wells.—But little needs to be said on this subject, in view of what has already been given. Perhaps the largest well that has been drilled in this county was on the Murlin farm, section

¹*Geol. Sur. of Ohio*, Vol. VI, p. 259.

1 of Center township. This is reported on seemingly good authority to have had an initial production of 1,200 barrels of oil per day, maintaining that rate for several weeks. It gradually decreased to 500 barrels, but continued producing at about that rate for some time. At present (August, 1902) it is very light. The well was drilled in 1895. Several wells in Union township started at from 600 to 800 barrels per day, and a large number at 100 or more. The gravity of the oil there is 38 degrees B. Other pools in the county made a poorer showing than that in the northeast corner. It has been found that the flowing wells were shorter lived than those which contained large quantities of salt-water. Taking the territory as a whole it is safe to say that it is long past its prime. Wells are being abandoned in comparatively large numbers, and the production of the county bids fair to decrease rapidly.

LUCAS COUNTY.

Early tests in this county were made for natural gas, and the results have already been given in the discussion of that fuel. Oil was found at a considerably later date. The territory is small, so that if it had never been discovered the production of the Trenton limestone field would not have been materially changed. Three townships contain oil; two of these lie east of Toledo and one west. A showing of oil can be secured at many places outside of the producing territory.

Monclova Township.—The territory here forms a strip extending from the Maumee river nearly due north, including parts of sections 32, 33, 28, 29, 20, 17 and 8. In width the strip nowhere exceeds one-half mile. It is an extension of the territory in the western part of Wood county.

Oregon Township.—This contains by far the larger part of the producing territory in Lucas county, including the whole or parts of sections 22, 23, 24, 19, 25, 26, 27, 28, 30, 31, 36, 35, 34, 2, 3, 5, 6, 7, 8, 11, 12, 18, 13, 14.

That the county contains oil in paying quantity seems to have been demonstrated for the first time about 1891, when a well was drilled on the Blodgett farm in section 2. The well was of the flowing type, but the oil was mixed with water, making the former of bad quality. Other wells were drilled about that time, but without marked success. The real production began with the completion of the Bartley well on section 2 in 1896. This well, according to Shafer Brothers, the drillers, had an initial production of 500 barrels of oil per day. The rock was shot later, but without beneficial results. Naturally a production of this type started considerable excitement, and greatly stimulated drilling. One year later a well was drilled that completely eclipsed the Bartley. This was the "Klondyke," situated in a marshy valley along the border of Irondale. The location was made by a forked stick, and when the Trenton had been penetrated 48 feet there was no show of oil or gas. The rock was then

shot with 120 quarts of nitro-glycerine, and oil began flowing at once. Tanks had not been provided, and the oil wasted for five hours. The first tank completed had a capacity of 250 barrels, and was filled in one hour and fifteen minutes. Then again the oil ran into the creek, and wasted. Seven hours later adequate tankage was provided. The well flowed during 12 days. In June, 1902, its production was 14 barrels per day. Other wells were at once begun in this vicinity, but all were small or failures; the second one, located about 500 feet from the "Klondyke," started at 3 barrels, and was abandoned one month later. The "Klondyke" gave the territory great advertising, and as a result wells were rapidly drilled. In 1902 work was being done at several localities, but no important additions were discovered.

Jerusalem Township.—The producing territory in this township is small. In sections 4 and 33 a small pool is found. Its length is about 2 miles and its maximum width less than one-half mile. A small pool crosses the southwest corner of section 9, extending southeast into Ottawa county, and northwest into section 8 of Oregon township, Lucas county. Immediately north of the west end of this pool another small one is found. It occupies parts of sections 4 and 9 of Jerusalem township and 5 and 8 of Oregon. From what has been said it is evident that the production of oil in this township is very small.

GEOLOGY OF THE COUNTY.

The topography is as flat and as uniform as is found in any county of the state. Along the lake shore there are extensive marshes, some of which have recently been drained, bidding fair to make excellent farming territory. The surface rocks in the eastern part of the county are principally Lower Helderberg, but the geological map of the state shows a narrow belt of the Niagara extending due north from Geneva to the lake, which is reached at Cedar Point. This belt, as sketched, lies east of the principal oil territory. The western part of the county has as surface rocks the Lower Helderberg and Corniferous limestones and the Ohio shales.

The Oil-rock.—The Trenton in the producing territory of the eastern half of the county lies from 740 to 800 feet below sea level. It is very unusual that oil is found at such depths in northwestern Ohio. The rock lies highest over the low fold which brings the Niagara to the surface. From that belt the Trenton dips east and west, and at the same time to the north, the greatest depth having been reported along the lake shore.

As a rule the oil-rock is penetrated 50 feet. Sometimes the oil is found at the top, but usually it lies below the so-called cap-rock. Shooting nearly always helps the wells; charges used range in size from 60 to 300 quarts.

Salt-water has never been a serious obstacle in the county. In fact, that found has generally been regarded as beneficial.

The life of the wells has presented considerable variation. Those near Ironville have in the main been remarkably short, some having been abandoned in a few months after completion. The wells farther east produce longer, and may rival in this respect the best territory in other counties.

OTTAWA COUNTY.

Drilling in this county began in 1886, the first well having been completed July 5. It was located at Oak Harbor, and the Trenton limestone was struck at 1,300 feet, or 720 below sea level. The well made a showing of oil and about 78,000 cubic feet of gas per day. Another well completed shortly afterwards met with still less success. Well No. 3, drilled late in 1886, yielded about 200,000 cubic feet of gas in 24 hours. A line was laid to the village and the use of this fuel begun.¹

From that early period, drilling has been done from time to time in the vicinity of Oak Harbor. The supply of gas has been continuous, but it is no longer adequate to meet the demands of the town. During the first six years the rate was 20 cents per thousand; then it was advanced to 30 cents with a possible rebate of 5, and 1902 was 35 cents straight.

In section 9, southeast of the village, 13 producing wells have been secured. These are about equally divided between gas and oil. The first of the producers of oil was drilled in 1898, and started at about 12 barrels per day; most of the others were sunk in 1899 and 1900. In 1902 the average daily production per well was about one and one-half barrels. Three small oil wells have also been secured about one mile east of Oak Harbor, on the north side of the river.

A number of additional tests of the Trenton have been made in this township; one on the Fred Miller farm, one and one-half miles southwest of Oak Harbor, made a showing of gas; one on the Applegate farm in section 8 gave a similar result; and the same is true of wells drilled on the Vogel farm in section 11, and on the Kreilich in section 20.

Several wells have been drilled in the vicinity of Port Clinton, and while all made a showing of oil or gas, none yielded these products in commercial quantities. The first of these wells, drilled in the winter of 1886-7, found the Trenton at about 1,080 feet below sea level. North from Oak Harbor the Trenton drops 100 feet in two and one-half miles.

Between Trowbridge and Limestone, in Benton township, a number of strong gas wells have been secured. The roar of the escaping gas could be heard at Oak Harbor, several miles distant, but salt-water soon ruined all.

At Elmore in Harris township a test was made in pioneer days of the industry in northwestern Ohio. The first well was dry, but the second

¹*Geol. Sur. of Ohio*, Vol. VI, p. 210-1.

yielded a little oil, enough to attract attention and to secure further tests. A number of wells have been sunk between Elmore and Oak Harbor, and oil secured in some, but all have now been abandoned.

Similar, though perhaps little better results have been had on the western side of the county. A well drilled at Geneva in 1887 found the Trenton at 660 feet below tide, and made a showing of oil with more gas. Just north of the village a number of wells have been drilled, the first about 1891. The rock pressure at that time is reported to have been about 225 pounds per square inch. Since 1892 the gas has been used in the village. Nearly a dozen additional wells have been drilled near this village, but all were dry. In the northern part of this township two pools of oil are found. One lies just east of Curtice, including parts of sections 8, 33 and 34; the other is longer, including parts of 14, 15, 26, 27, 34, 35, 2, 3, 10, 11 and 14.

WYANDOT COUNTY.

The oil territory in this county extends from near Carey southeast within two miles of Upper Sandusky, and as shown by the map consists of several small pools, two of which number less than a half dozen wells each.

Crawford Township.—This contains two small pools and part of a large one, the latter lying principally in Salem township. In 1902 the productive territory was limited to sections 20, 27 and 35, but formerly it was considerably larger.

Work began at an early day, probably in 1886. Here as elsewhere the search was for natural gas. The Trenton limestone was found at 1,326 feet or 513 feet below tide level, and a small flow of gas secured. Other wells, drilled in the same locality, gave better results and consequently the village soon had an adequate supply of gas. About 1888 oil was discovered on the Kinley farm, section 1 of Salem township, and from that point the drill moved north into Crawford. Drilling has been done from time to time in the township ever since. Probably 50 per cent. of the producers have now (1902) been abandoned, and doubtless others soon will be. Over 40 dry holes have been sunk, so that it is safe to say that the township has been thoroughly tested.

Salem Township.—This township lies south of Crawford. The producing territory includes parts of sections 1, 2 and 12. As has already been stated oil in Wyandot county was first discovered in this township, and from here the drill moved into adjacent townships. The initial well flowed about five hundred barrels per day; in 1900 it was yielding two barrels, and was still producing in 1902. About 1890 a well drilled on the Krebs farm, section 1, began flowing at the reported rate of 1200 barrels of oil per day, making it the largest ever drilled in the county. In July, 1902, its daily production was two barrels. Work has been done from time to time in the township since oil was discovered.

Crane Township.—Early in 1886 the Trenton was tested at Upper Sandusky and found dry. Later oil was secured in sections 6, 7 and 19; that in 6 and 7 is an extension of the Salem township pool; and that in 19 is a small outlier. The dry holes have been more numerous than the producing wells; consequently the township has added little or nothing to the wealth of the country.

GEOLOGY OF THE COUNTY.

The surface of the county is level or gently undulating. On the western side the Niagara limestone forms a narrow strip running north and south. On the eastern side there is a parallel strip about equal in width of the Corniferous limestone, and between the two a broad area of the Lower Helderberg. The succession of strata underground at Carey is as follows:¹

	Feet.
Drift	2
Lower Helderberg and Niagara limestones.....	257
Niagara shale and Clinton.....	65
Medina shales	52
Cincinnati (Hudson River) shales.....	650
Utica shales	300
Trenton at	1,326

The Trenton was found to lie 515 feet below tide level; at Upper Sandusky it is about 480 feet below, and at Nevada, near the Crawford county line, about 830 below. This shows a rapid descent east from Upper Sandusky. In fact the rocks of the county appear to lie quite uneven. Thus from what has been stated above it is seen that at Upper Sandusky the Trenton lies 35 feet higher than at Carey, though the former place lies east and south of the latter. This indicates an arch in the vicinity of Upper Sandusky. Another disturbance is found in section 34 of Crawford township, where the Trenton is reported to vary in position 100 feet in less than a mile.

In the vicinity of Carey the Trenton was found to be quite free from salt-water, but about one mile southwest of that town a heavy pool of brine was encountered, that sometimes ran from the well. Fine oil wells were secured in this. Southeast from Carey brine was found almost everywhere. The water and oil were mixed, and consequently were pumped together.

VAN WERT COUNTY.

Oil territory in this county is not extensive, notwithstanding that it is found in five townships. The Allen county fields extend into Van Wert from the east and the Mercer from the south. Early wells were drilled wholly for gas, and were practically failures.

¹*Geol. Sur. of Ohio*, Vol. VI, p. 204.

Jennings Township.—This has the largest area of producing territory in the county. The Allen county fields extend into this township at three points; sections 4 and 9, 21, 4 and 34, but the combined areas of the three do not exceed one square mile. In the northeast corner of the township a much larger area is found, comprising parts of sections 6, 7, 8, 17 and 18. This extends west into York township, and is known as the Venedocia field. In the southwest corner of the township under consideration an extension of the Mercer county territory is found. This comprises section 7 and parts of sections 5, 6 and 18. The Trenton is found usually at depths ranging from 1,175 to 1,200 feet.

The development of this township began about the year 1890. Early wells showed much salt-water, and this discouraged drilling. However, oil men finding that the brine could be handled, made further tests and were successful. By 1896 work in the northwestern corner of the township had ceased, but was renewed in 1900. The territory in the southwest corner forms part of the Menden field. This township has now been thoroughly tested, and no important addition needs be looked for. However, when the day arrives so that small wells which cannot now be operated with profit can be so operated, then considerable drilling may again be done. Many of the pioneer wells have been abandoned, and it appears that the township is now past its prime.

York Township.—In the northeast corner of this township producing territory is found in sections 1, 2, 3, 11, 12, 13 and 14, but the area is only about two square miles. In the southeast corner a small extension of the Menden pool is found in sections 25, 35 and 36. About three miles due west of this a very small pool is found in section 33. The oil rock is found at depths varying ordinarily from 1,180 to 1,225 feet.

Work in this township began near Venedocia, in the northeast corner about 1890, and has been continued irregularly ever since. Since 1900 many wells have been drilled in that vicinity, and as late as the summer of 1902 work was active. Many of the early wells have already been abandoned. The late wells commonly have an initial production ranging from 15 to 25 barrels per day. The territory in the southeast corner of the township was drilled late in the history of the Menden field.

Ridge Township.—Oil territory in this township is restricted to the southeast corner, where it occupies small parts of sections 33, 34, 35 and 36. The total area is less than one square mile. It comprises the northern part of the Venedocia field. In sections 28, 21 and 20 several gas wells are found. These supply Van Wert, as has been stated elsewhere in this volume. The first oil well in the township was drilled in November, 1901.

Liberty Township.—This contains several small pools, the combined area of which does not exceed two square miles. One of these extends across the township line into Willshire. In the extreme southwest corner of Liberty there is found a very small extension of one of the Mercer coun-

ty pools. The sections are 26, 27, 34, 21, 16, 17, 18, 20, 19, 30 and 31. These wells have been drilled ~~comparatively~~ recently. The depth to the Trenton is similar to that in Jennings and Liberty townships.

GEOLOGY OF THE COUNTY.

The conspicuous surface features of the county are two in number; one of these is a beach of glacial-lake Erie, which extends across the northern part of the county. This is a low ridge of sand and fine gravel rising a few feet above the general level. The second feature is a moraine extending east and west across the south side of the county. This is a ridge of clay and gravel, and while rather flat is still considerably higher and wider than the lake beach. With the exception of these two cases the topography of the county is exceedingly flat. The surface rocks in the southwest corner belong to the Niagara, those in all other parts to the Lower Helderberg.

The following record of a well at Van Wert shows the succession and thickness of strata:¹

	Feet.
Drift	32
Waterlime (Lower Helderberg)	148
Niagara limestone	185
Niagara shales	15
Clinton limestone	40
Medina and Cincinnati (Hudson River) shales (blue)	510
Utica shales (dark)	290
Trenton at	1,220

The top of the Trenton was found at about 435 feet below tide level. In the eastern part of the county, near Delphos, the same formation was found at 453 feet below tide. This shows the Trenton lying nearly horizontal. Comparing these figures with those found at Celina, in the county to the south, shows a dip northward of about 200 feet. Even this, however, is a very gentle descent. It appears from what has been said that the position of the Trenton rock in this county corresponds very closely with that found in adjacent counties. The depths at which the formation is struck ranges ordinarily from 1,120 feet to 1,260. The pay-rock is comparatively shallow, being found ordinarily at depths of less than 35 feet in the Trenton. Thus far deeper pays have not been found, though no extensive search has been made for them.

Much of the oil found is of poor quality, having a very dark color, and high specific gravity, the latter dropping to 35 degrees B., and occasionally still lower. The size of the wells has been in keeping with the quality of the product. Rarely has the initial production reached 200 barrels per day. The life of the wells appears to be shorter than in the coun-

¹*Geol. Sur. of Ohio*, Vol. VI, p. 239.

ties farther east, so that, all things considered, Van Wert cannot be regarded as having contributed materially to this form of wealth.

Salt-water has been found very generally with the oil. Sometimes it has been so abundant as to prove an expensive obstacle. The county appears to form the border on the northwest for oil production, and possibly this may be responsible for the discouraging features named.

Many efforts have been made to develop a large pool in Van Wert county, but without success. Nearly everywhere a show of oil or gas is secured, and this has kept the drill busy. Probably other small pools will be discovered, but it is safe to say that no large areas will be found.

SHELBY COUNTY.

The only oil or gas producing territory in this county is found in sections 7, 18, 6, 8, 5, 4, 11, 32 and 33 of Van Buren township. The length of the pool is three and one-half miles, and the maximum width three-quarters of a mile. The pool is an extension of that found in German township, Auglaize county, and was opened in the summer of 1898. At first a few of the best wells started at 100 barrels per day, but so rapid has been the decline that in August, 1902, the pool did not average one barrel each per well.

In 1897 two wells were drilled near Kettleville, on the south side of section 11. One of them began flowing 100 barrels per day, and a year later was producing 10 barrels. In the summer of 1902 it was yielding three barrels daily. The other well was smaller. No salt-water was found. One of these wells found 500 feet of drift and the other 380 feet.

On the margin of the producing territory salt-water is very abundant; but near the center of the pool where as a rule the best wells are found it is much less troublesome. The rock is quite spotted, dry holes being scattered among producing wells. The Trenton appears to lie nearly level. The oil is very dark and heavy, its specific gravity being 34 degrees B.

As has already been noted in the discussion of Auglaize county, the deep pre-glacial channel, which has been there outlined, extends across the northeast corner of this county. It is shown by drive pipes from 300 to 400 feet or more in length.

DARKE COUNTY.

Near Yorkshire, in the northern part of the county, several small oil and gas wells have been secured. The drilling was done in 1897-8. Owing, however, to the low price of oil the wells were not profitable. Quite recently the territory has been re-leased, and it seems probable that it will be thoroughly tested in the near future. Wells have been sunk at numerous localities in the county, but the results in all cases have been unsatisfactory.

PUTNAM COUNTY.

A small pool of oil has been discovered in the southeastern corner of this county. It occupies part of section 26, Riley township, and the development began in 1896. Drilling has been done from time to time since that year.

The Trenton is reached at from 1285-95 feet, the oil lying near the top of the formation. About 450 feet of casing are used. The largest wells had an initial production of perhaps 65 barrels per day. Near the margin of the pools the wells were much smaller, and the production of brine correspondingly larger. From the dry holes sunk it seems probable that the area of productive territory has been determined, and consequently very little can be expected in the future.

Tests were made at Ottawa and Columbus Grove in 1885, and Leipsic and Kalida in 1886. All were failures as far as securing oil or gas in commercial quantities was concerned. Since that time many wells have been drilled in the county. Nearly every township has been tested, and in several a number of wells have been sunk. Frequently a show of oil or gas was secured, but there has been practically nothing to compensate for the time and money expended. It seems safe to say that no large reservoir of oil or gas can be expected in the county. It may be, however, that in years to come, when the price of oil is much higher than at present, that the rocks in Putnam county will yield a profitable supply of crude oil.

PAULDING COUNTY.

In the summer of 1902 two small oil wells were drilled near the town Paulding, and four gas wells had previously been completed southwest of that town. These supply the place named with fuel. In all probability the Trenton limestone in the county under consideration will be found to contain quite commonly small but unprofitable quantities of oil or gas.

CHAPTER III.

THE CLINTON FORMATION AS A SOURCE OF OIL AND GAS.

Introduction.—Oil or gas has been secured in these rocks at a number of places. In the main, however, the yield has been very small, often a mere showing. The only pool of oil having commercial importance that has yet been discovered lies in the northern part of Vinton county, and the reader is referred to that county for details. A small well has been secured between Junction City and New Lexington, in Perry county, and another well is now under way. Small flows of gas have been secured in the Clinton at a number of points in northwestern Ohio, especially at Fremont, Sandusky county. A few scattering wells have been drilled in Vinton county, but the one important field lies in central Ohio. No further notice will be given the scattering wells in this chapter, and hence the theme for discussion is the fields in the central part of the state.

THE CENTRAL OHIO NATURAL GAS FIELDS.

Four fairly distinct reservoirs of gas have been discovered in central Ohio. However, their geological relations are similar, while geographically they are closely related, and for these reasons all will be considered together. In other words the several reservoirs will be regarded merely as parts of one large field.

Location and Area.—At the present time these fields consist of two parts, a southern one commonly known as Sugar Grove, and a northern one known as Homer. Between these, two additional reservoirs have been discovered, but both have long been exhausted. One lay at Thurston, Fairfield county, and the other in the vicinity of Newark, Licking county.

By far the most important reservoir is that surrounding the village of Sugar Grove. It includes portions of the following townships in Fairfield county; Pleasant, Berne, Rush Creek and Madison. In the last two, however, very few wells are found. Hocking county, lying to the south, has producing wells in the following townships; Good Hope, Laurel and Marion. The length of the field as developed in 1902 was 16 miles, and the maximum width 11 miles. The longer axis runs north and south. Lying north of this field is that of Thurston, which as has already been stated, has long been exhausted. Continuing due north the old Newark

field is skirted along its western edge, and finally the Homer reservoir reached. The latter as developed in the fall of 1902 contained parts of Burlington, Bennington, Washington and McKean townships of Licking county, Milford, Miller and Morgan townships of Knox county. A well has recently been drilled in the northwestern corner of Clay township, and one in the northern part of Union.

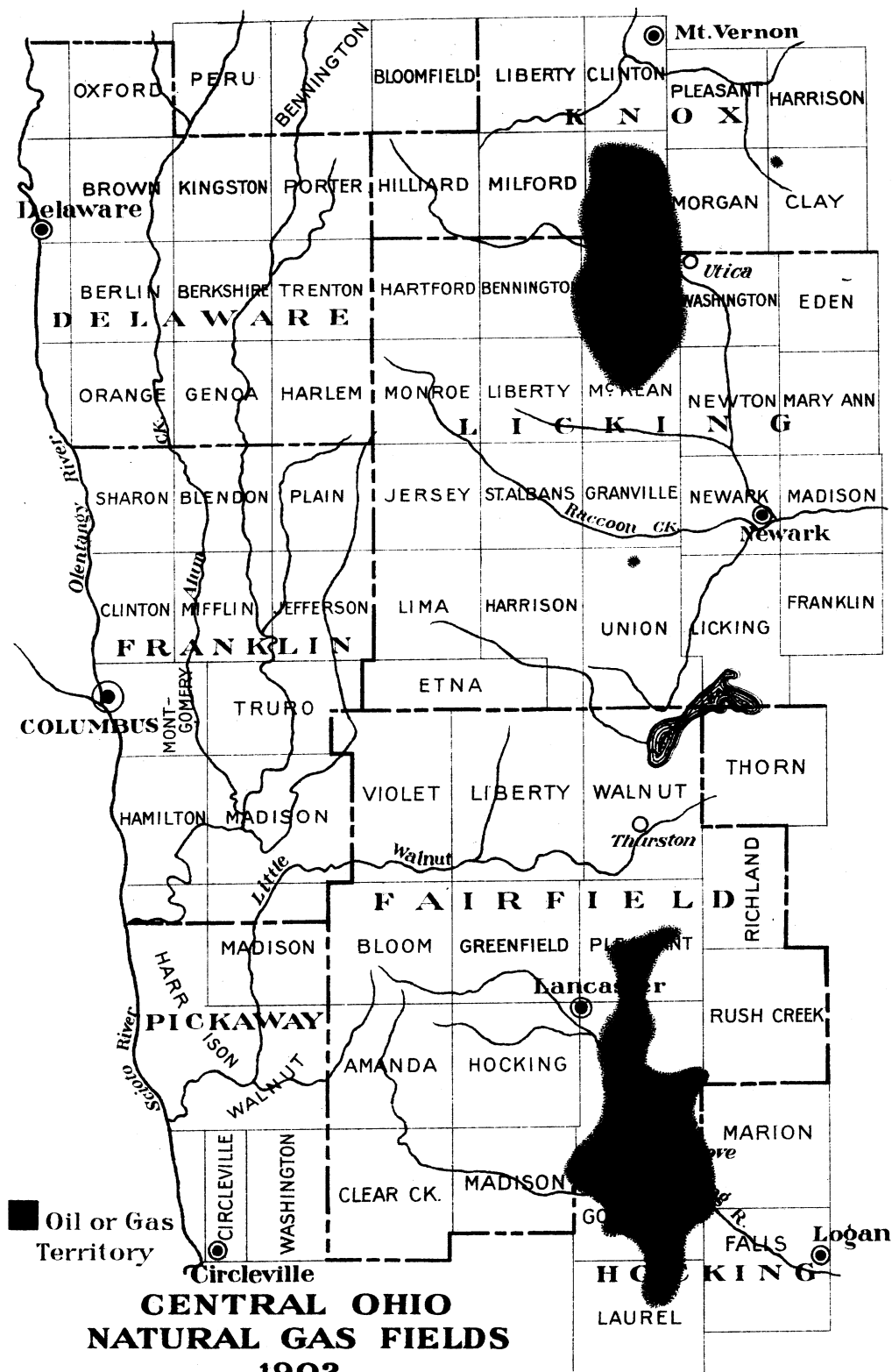
It is evident from what has been said that the gas fields of central Ohio extend north and south, the distance being about 60 miles. It must not be understood, however, that at any one time the producing territory has formed a continuous strip of this length. It is worthy of note at this point, that in the northern part of Vinton county, about 12 miles south of the southern limit of the gas belt, a small pool of oil has recently been discovered in the Clinton sand. Still later a small oil well has been secured in the same formation near Junction City, about 20 miles east of Lancaster.

History and Development.—No other event in the history of Ohio has so stimulated the search for underground wealth as did the discovery of natural gas at Findlay in 1884. From that city the drill has moved out in all directions until every county in the state has been tested; in some the wells may be reckoned by the score, yes, by the thousands. In the main these tests have produced negative results only, and still they have formed the basis of two of the state's principal sources of wealth. The Findlay discovery was followed in 1885 by tapping the immense volume of oil stored in the Trenton limestone, and two years later by the discovery of gas at Lancaster.

The first step towards testing the rocks in the vicinity of Lancaster was taken December 2, 1885, when the Lancaster Natural Gas Company was incorporated.¹ The capital stock was \$50,000 in shares of \$50 each. On the date just mentioned the company organized by electing the following officers: President, E. L. Slocum; Vice-President, A. Getz; Secretary, H. B. Peters; Treasurer, N. Butler.

The directors included, in addition to the officers, H. C. Drinkle, J. R. Mumaugh, J. G. Reeves, E. Becker and George Lutz. In May, 1886, the company contracted with Albert Smith to drill a well, and work was immediately begun, the objective horizon being the Trenton limestone which was then yielding such astonishing results in northwestern Ohio. The location was on a lot owned by the president of the company and was situated near the Hocking Valley station. It was soon demonstrated that the territory is covered with a heavy mantle of drift. This retarded the work, and of course increased the expense, so that stockholders were required to pay ten dollars per share more than the face value of their stock. Gas was finally struck February 1, 1887, at a depth of 1,957 feet. On the tenth of the same month the flow was measured at the casing head and found to be 74,880 cubic feet per day. However, the well contained a large quantity of salt

¹*Lancaster Eagle*, June 21, 1888.



water, and the pressure of this greatly weakened the flow of gas. Later the well was shot with 100 quarts of nitro-glycerine, and the gas piped to the works of the Hocking Valley Manufacturing Company. The great expense of drilling, and the small production, together with the many other uncertain elements, such as the life of the wells, continuity of the gas rock, etc., made progress slow. That the citizens of Lancaster were not greatly discouraged, however, is shown by the fact that on April 7, 1887, another organization, the Mt. Pleasant Natural Gas and Oil Company was formed. The officers were: President, George W. Welsh; Vice-President, S. H. Beck; Treasurer, H. B. Peters; Secretary, Daniel Danehy. The Board of Directors consisted of the officers and E. L. Slocum, J. T. Busby, H. C. Drinkle, James McSweeney and A. H. Middletown.

About the same time the East End Natural Gas and Oil Company was formed with a capital stock of \$5,000.

The second well in the territory was drilled on the land of Joseph C. Kinkead, near the foot of Mt. Pleasant. The gas rock was struck October 5, 1887, at a depth of 1989 feet. Nine days later the flow of gas was measured and found to be 792,000 cubic feet per day, through a four and one-half inch casing. The third well was located about one mile southeast of the city. The gas rock was struck at a depth of 2020 feet, October 11, 1887, and the production is reported to have been 1,000,000 cubic feet in 24 hours.

The companies owning these wells next began to look for a market for their fuel. The most natural one was the city of Lancaster, and on Monday evening, October 23, 1887, the directors of the company owning the well at the foot of Mt. Pleasant asked the city council for a franchise permitting the company to pipe the city. This precipitated a lively debate in which the representatives of the several companies took part. Finally the matter was referred to the committee on streets and alleys, but before a decision could be reached the three companies consolidated, the name being the Lancaster Gas and Oil Company No 1. Officers of this organization were chosen December 5, 1887, as follows: President, P. W. Bininger; Vice-President, C. P. Noll; Treasurer, F. X. Winter; Secretary, W. T. McCleneghan.

On the 18th of the same month the company was authorized to pipe the principal parts of the city. A committee was appointed to visit Findlay and other places where natural gas was in use, the object being to secure information as to the best and safest methods of handling the new fuel. No pains were spared to make the company a success. The result was that within a month after the issuing of permits had begun, there were 500 gas fires in the city. Everybody was calling for gas, making the demand greater than the company could supply, owing to the heavy expense of laying the necessary mains. Fortunately it had been provided when the three companies consolidated that if at any time the city saw fit to purchase

the plant it might do so at actual cost plus six per cent. interest on the investment. To make this possible a law was enacted by the legislature permitting the city to submit to the people a proposition to bond the corporation for \$50,000 to purchase the existing natural gas plant, drill new wells, lay mains, etc. The election was held April 30, 1888, the vote resulting 1260 in favor of and 25 against the proposition. Bonds bearing six per cent. interest were at once sold. These were payable from 1892 to 1902, and all found ready buyers. The cost of the plant secured in this manner was about \$24,000, the remainder of the money having been used for drilling new wells, laying mains, etc.¹

During the winter of 1888 and 1889 the supply of gas was not equal to the demand. Thus far all the wells secured were small, while the call for fuel had become very heavy. Under such conditions there was considerable dissatisfaction, and many doubted the wisdom of having bonded the corporation for so large a sum. In fact the future of the field seemed altogether problematical. During this period of doubt and insufficient gas an event occurred which completely changed the aspect of affairs.

This was the great success of the Mithoff well, which was drilled by Theodore Mithoff within the corporation limits, the object being to secure a supply of gas for his machine shop. The gas rock was reached February 17, 1889, and a good flow at once secured.² The drill was kept at work and the volume of gas increased rapidly as the rock was penetrated to a greater and greater depth, until the open flow rose to 12,000,000 cubic feet in 24 hours. This was one of the finest gas wells that had ever been drilled up to that time in this or any other county. The citizens of Lancaster were quick to see what this meant for the city, and to properly give vent to their feelings a jollification was planned, with torch light parade, speeches, etc. Arrangements were made to connect this well "The Old Man Himself" with the city mains, thus providing an ample supply of gas.

Another famous well was completed that year. It was located on the county fair grounds, and had an initial open flow of about 10,000,000 cubic feet in 24 hours. A line was laid around the race track that fall, and "By this means the track was lighted up at night as never race track was lighted before, and the trials of speed went forward under this wanton illumination. The idea was novel and the scene unique and brilliant, but the waste was barbaric all the same."³ Other wells were drilled with varying results; still the quantity of gas at the command of the city was large and the next thing was to find a market for it. "The strange folly that seems bound up in the heart of a municipal corporation when it obtains a good supply of gas, that it must find some one who can use the fuel up in the largest way and most rapidly to whom to give it, without money and without price, broke out also in Lancaster. An ill-omened arch, bearing

¹*Ohio Eagle*, Aug. 16 and Sept. 16, 1889.

²*Ibid*, Feb. 21, 1889.

³*Geol. Sur. of Ohio*, First Ann. Rep, 1890, p. 237.

the illuminated inscription 'Free Gas to Manufacturers.' spans the main street of the town at the railroad crossing."¹

With the increasing demand and the decline in the production of the various wells, the company was obliged to continue drilling. This necessitated leasing additional territory, and since this could be secured only at increasing distances from the city, the expenses of the company have been increasing. By September, 1902, the company had drilled all told about 36 wells, according to data furnished by G. W. Trimble, Superintendent. Of these 18 were producing at that date, 8 had been abandoned and 10 were dry. All of the producing wells, with one exception, are in Berne township. On the authority of the officer just named the company was supplying 10,000,000 cubic feet of gas per day during the coldest weather in the winter of 1901-2, and this did not fully meet the demand. Of this quantity about 20 per cent. went to manufactories, the Columbus Plate Window Glass Company alone using 1,000,000 cubic feet. In May, 1902, the company was supplying 3,000,000 cubic feet per 24 hours, but only one-third of that was used for domestic purposes. In the following fall (1902) the superintendent estimated that the company could supply from 7,000,000 to 8,000,000 cubic feet per day.

During all the past years no meters have been used, with the result that a tremendous quantity of fuel has been wasted. Rates, adopted March 19, 1889, have been as follows:

Cook Stoves—Domestic.

(For Annual contract service only.)

No. 5 Mixer . . .	\$12.00 per annum, payable \$1.00 each month
No. 7 Mixer . . .	\$18.00 per annum, payable \$1.50 each month

Laundry Stove—Domestic.

(Where Cooking Stove is furnished also.)

No. 5 Mixer	50c per month
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Heating Stoves and Grates—Domestic.

(For continuous service from October 1. to May 1.)

No. 5 Mixer	\$1.00 per month
No. 7 Mixer	\$1.50 per month

For less than seven months' service, higher rates will be charged.

Furnaces and Baltimore Heaters—Domestic.

(Where Heating Stoves and Grates are furnished also.—Continuous service from October 1 to May 1.)

No. 7 Mixer	\$2.00 per month
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¹*Geol. Sur. of Ohio, First Ann. Rept., 1890, p. 236.*

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Business Rooms.

No. 5 Mixer.....	\$2.00 per month
No. 7 Mixer.....	\$3.00 per month

The rate for ordinary sized rooms used for business offices will be the same as Domestic Heating Stoves.

Hotel and Restaurant Cooking Ranges.

(For annual contract service only.)

No. 5 Mixer.....	\$1.50 per month
No. 7 Mixer.....	2.00 per month
No. 9 Mixer.....	3.00 per month

The rate for boilers varied from \$8 to \$60 per month. The window glass company has paid as high as \$5,500 for a year of eight months.

The scarcity of the supply and the unfavorable outlook for good territory at last brought the citizens to their senses. In the summer and fall of 1902 meters were introduced, thus putting an end to the untold waste of the last 15 years. The terms are most generous, being ten cents per thousand for domestic purposes and six cents for factories. It is believed that this will greatly diminish the quantity of gas burned, without materially increasing the expense of the consumer, or depriving the poorest of the use of the fuel. Further it will by decreasing the quantity of gas burned, diminish the expense of the company and also prolong the life of the field. The plant has been a good investment for the corporation. It has paid the city debt, the annual payment reaching as high as \$35,000. Further, with the exception of \$15,000 still due, it has paid for the handsome new city hall costing \$83,000. The past year, however, has not been so successful. The receipts have been favorable, but the expense has been heavy. This resulted from the necessity of drilling new wells, several being dry, and the purchase of long strings of pipe. The bonds issued to purchase and extend the plant have all been paid from the gas receipts. In April, 1902, two propositions were submitted to the voters of the town:

1. The issuing of \$40,000 worth of bonds for the erection of a municipal natural gas pumping station.
2. The issuing of \$20,000 worth of bonds to drill wells, lay pipe, etc.

Both propositions were carried, and the bonds for drilling new wells were quickly sold, but those for the erection of a pumping station found no buyers, owing to doubt as to their legality.

THE NEWARK FIELD.

After the discovery at Findlay, Newark did not long delay drilling for gas. The first well was begun probably in 1885, and was located along the western edge of the town. Progress was very slow; the work was done with pole tools, and besides the 236 feet of drift proved troublesome.

A show of gas was found in the Berea, but the drill was forced through 900 feet of the underlying shales without better results. In October, 1886, a well was begun on the property of the Everett Glass Company. All went well until the drill had descended to a depth of 2,240 feet when a heavy flow of brine was encountered and the driller, unwilling to provide so long a string of casing, abandoned the well. Several members of the company were not willing to give up, however, and a new driller was secured who resumed work, and at a depth of 2,385 feet found a small flow of gas. These tests, while not an unqualified success, proved the existence of a field, and this was enough to insure further exploration.

The third well was soon begun. A flow of perhaps 300,000 cubic feet per day was secured, and this was at once piped to the works of the Everett Glass Company. Other wells were drilled in rapid succession and by 1889 the supply not only met the demands of the glass house, but was sufficiently large to warrant piping the city. The wells, however, were all small, the largest probably not exceeding 1,000,000 cubic feet per day; so that the supply in the winter of 1889-90 was not equal to the demand.¹ This stimulated drilling, and during the ensuing 15 years about 24 wells, one-fourth of which were dry, were drilled in the vicinity of Newark. Later the company secured a strip of territory between Newark and Thurston on which a number of producers were secured. At first it was thought that the supply would be equal to all demands, but that was soon found to be a mistake, and its use in factories was discouraged. In the fall of 1901 only two of the wells were still producing, and these were very small. They were drilled in 1891. With the decrease in the local production the city was compelled to look elsewhere for a supply. This was obtained from the Sugar Grove field, the fuel being furnished by the Logan Natural Gas and Fuel Company. On August 19, 1902, The Peoples Natural and Artificial Gas Light and Fuel Company was granted the right to pipe the city. The company's gas territory lies in the Homer field, and it is too early to say at the present time how much of a factor the new company will be in supplying Newark with fuel.

THE THURSTON FIELD.

The discovery of gas at Thurston resulted directly from that at Lancaster and Newark. The place mentioned lies midway between the two cities just named, and it was a very natural thing for the driller to conclude that producing wells might be secured at such a place. The first well was drilled in the spring of 1888 on the Bush farm, near the railroad station, and made just enough gas to encourage the operator to make further exploration. Later a well was drilled about one mile farther east, and it proved to be a large producer. It is reported by J. O. Johnson, Superin-

¹The foregoing account is merely an abstract from *Dr. Orton's Reports*, Vol. VI, p. 370-1; *First Ann. Rept.* (1890, p. 237-240).

tendent of the Central Ohio Natural Gas and Fuel Company, to have had a closed pressure of 700 pounds per square inch and an open flow of 7,000,000 cubic feet in 24 hours. It is worthy of mention that these two wells were drilled by Columbus citizens, an organization that later developed into the Central Ohio Natural Gas and Fuel Company.

The success of the second well insured the rapid development of the field, and by the summer of 1889 a sufficient volume of gas had been secured to warrant laying a line to Columbus. The council of that city readily granted a franchise, and in December of the same year a ten inch line had been laid to the city. Early in January, 1890, natural gas was supplied to Columbus for the first time. Unfortunately its use was not restricted to domestic purposes, and by November, 1890, the pressure in the field had so decreased that it was found necessary to discontinue the supply to factories. By January 15, 1891, the fuel was so nearly exhausted that the company was compelled to discontinue supplying Columbus, and from that time very little gas has been piped from the Thurston field.

The territory had a length of three and one-half miles, and a width of one-half mile. The wells near the middle of this territory had an initial production ranging from 5,000,000 to 7,000,000 cubic feet in 24 hours, with a maximum of perhaps 8,000,000. Towards the margin of the belt the wells decreased in size. In the spring of 1902 all but two had been abandoned, and neither of these had been connected with the line for nine years. In fact the pressure in the wells is less than that in the line. The short life of the field resulted from the small area and the heavy demands made upon it. The quantity of gas contained in any field is limited, and the duration of this supply is determined by the demand. Double the latter and the life of the field is cut in two.

THE SUGAR GROVE FIELD.

This is by far the richest part of the Central Ohio natural gas fields, and hence it will be considered more fully than any of the others. Its history has already been touched in the discussion of the development about Lancaster. Perhaps the best procedure will be to consider first the companies that are piping gas from the territory. These are the following:

1. The Lancaster Natural Gas and Oil Company, No. 1.
2. The Central Ohio Natural Gas and Fuel Company.
3. The Ohio Transportation Company.
4. The Logan Natural Gas and Fuel Company.
5. The Ohio Fuel Supply Company.
6. The Northwestern Ohio Gas Company.
7. The Federal Gas and Fuel Company.
8. The Cole Glass Factory, and two or three smaller organizations.

The Central Ohio Natural Gas and Fuel Company.—The first of the companies enumerated above has already been discussed and hence will not be further noticed. The Central Ohio Natural Gas and Fuel Company was incorporated July 1, 1889, with a capital stock of \$750,000. The stockholders were principally Columbus citizens, and the object of the organization was to supply that city with natural gas. As has already been narrated the company obtained its first supply from the Thurston field, but the decrease in pressure was so rapid that the company was compelled to practically abandon the territory January 15, 1891. In February of that year the organization completed a well on the Zink farm about two miles north of Lancaster, and was rewarded with a production of 6,000,000 cubic feet of gas per day. Other wells were at once begun and more than a dozen were drilled in that vicinity. This strip runs due east and west across the southern part of Pleasant township. This discovery again filled the lines of the company, and May 1, 1891, Columbus was once more enjoying the finest fuel in the world. From that date the supply has been maintained without interruption. The third step in the development of the company was taken late in 1893, when a well was completed near Sugar Grove. This connected Columbus with the finest reservoir of gas yet found in the state. With the development of the territory around Sugar Grove the company has been able to cut off the wells in Pleasant township. In this manner it is saving that territory. When the Sugar Grove field falls too low to yield an adequate supply the wells in Pleasant township will again be connected with the company's lines. The rock pressure in this part of the field was originally 700 pounds. At present (1902) it ranges from 500 to 600 pounds. In 1901 the company began work in the Homer field, and by September of that year had completed 13 wells, one only of which was dry. A line was laid to Columbus in the fall of 1902, and the use of gas from the new field at once begun.

In the fall of 1900 the company erected a pumping station at a point between Lancaster and Sugar Grove, the pressure of the field having fallen so low that it was no longer able to supply a city so far distant as Columbus. The power consists of four engines connected tandem fashion, the combined horse power being 1,000. A pressure of from 60 to 325 pounds is maintained in the line. The latter has a diameter of 12 inches from Columbus to Canal Winchester, and of 10 inches from the last place to the pump station.

The total number of wells drilled by this company to September, 1902, was about 110.

The price of natural gas in Columbus was fixed by act of the city council December 17, 1888. This was before the Columbus Natural Gas and Fuel Company was granted a franchise to pipe the city. The rates established were as follows:

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For Cooking.

From November 1 to May 1.

From May 1 to November 1.

	Monthly Charges	If paid before the 10th			Monthly Charges	If paid before the 10th	
		Dis- count	Net Ch'ges			Dis- count	Net Ch'ges
No. 7 Mixer...	\$2.78	.28	\$2.50	No. 7 Mixer...	\$1.66	.16	\$1.50
No. 5 Mixer...	2.22	.22	2.00	No. 5 Mixer...	1.39	.14	1.25
No. 3 Mixer...	1.67	.17	1.50	No. 3 Mixer...	.83	.08	.75

For Large Cooking Range.

No. 9 Mixer...	\$3.33	.33	\$3.00	No. 9 Mixer...	\$2.22	.22	\$2.00
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For Laundry.

When gas is furnished for cook stove also.

	Monthly Charges	Dis- count	Net Charges		Monthly Charges	Dis- count	Net Charges
No. 7 Mixer...	\$1.11	.11	\$1.00	No. 5 Mixer...	\$0.83	.08	\$0.75

Manufacturer's rates for fuel shall be 75 per cent. of the cost of coal and no more.

For Heating.

No. 7 Mixer.

	Monthly Charges	If paid before the 10th			Annual Charges	If paid before the 10th	
		Dis- count	Net Ch'ges			Dis- count	Net Ch'ges
1st Mixer.....	\$5.00	.50	\$4.50	1st Mixer..	\$30.00	\$3.00	\$27.00
2d Mixer.....	4.44	.44	4.00	2d Mixer..	26.44	2.64	24.00
3d Mixer.....	3.89	.39	3.50	3d Mixer..	23.34	2.34	21.00
4th Mixer.....	3.33	.33	3.00	4th Mixer..	19.98	1.98	18.00
5th Mixer.....	2.78	.28	2.50	5th Mixer..	16.68	1.68	15.00
6th Mixer.....	2.22	.22	2.00	6th Mixer..	13.32	1.32	12.00

No. 5 Mixer.

1st Mixer.....	\$3.89	.39	\$3.50	1st Mixer..	\$23.34	\$2.34	\$21.00
2d Mixer.....	3.33	.33	3.00	2d Mixer..	19.98	1.98	18.00
3d Mixer.....	2.78	.28	2.50	3d Mixer..	16.68	1.68	15.00
4th Mixer.....	2.22	.22	2.00	4th Mixer..	13.32	1.32	12.00
5th Mixer.....	1.66	.16	1.50	5th Mixer..	9.96	.96	9.00
6th Mixer.....	1.39	.14	1.25	6th Mixer..	8.34	.84	7.50

No. 3 Mixer.

For heating small rooms and for special purposes.

	Monthly Charges	If paid before the 10th	
		Discount	Net Charges
1st Mixer	\$2.22	.22	\$2.00
2d Mixer	1.66	.16	1.50

Furnaces.

	Monthly Charges	If paid before the 10th		Annual Contracts		
		Dis- count	Net Ch'ges	Annual Charges	Dis- count	Net Ch'ges
"A" Mixer, 21-inch fire pot..	\$6.95	\$0.70	\$6.25	\$41.70	\$4.20	\$37.50
"B" Mixer, 24-inch fire pot..	8.66	.86	7.80	51.96	5.16	46.80
"C" Mixer, 26-inch fire pot..	9.44	.94	8.50	56.64	5.64	51.00
"D" Mixer, 28-inch fire pot..	10.00	1.00	9.00	60.00	6.00	54.00
"E" Mixer, 30-inch fire pot..	11.66	1.16	10.50	69.96	6.96	63.00
"F" Mixer, 35-inch fire pot..	13.89	1.39	12.50	83.34	8.34	75.00

July 29, 1889, the city council amended its previous act fixing the rates for natural gas in Columbus by providing that if the company or companies adopt the meter system they shall charge twelve and one-half cents per thousand cubic feet, and for the meter \$3.00 per year. This act like the previous one was to stand ten years. When the company shut down its plant January 15, 1891, only a small number of meters were in use, and these were looked upon as experiments. This act also gave the consent of the city to the transfer from the Columbus Natural Gas and Fuel Company of its privileges secured under the act of July 29, 1889, to the Central Ohio Natural Gas and Fuel Company. The first named organization, while the pioneer in the field, seems to have done little more than secure the franchise. On March 30, 1891, the city council repealed these two ordinances and established a meter rate. This simply fixed the price of gas at twenty-five cents per thousand cubic feet, and of the meter at \$3.00 per year. The term was for ten years and no further change in price was made until the close of that period.

The next and last change in the price of natural gas was made July 1, 1901. This fixed the rate for a period of ten years. The ordinance is given below:

AN ORDINANCE, No. 18,338, To fix the price to be charged by natural gas companies for gas in the city of Columbus, Ohio, for the period of ten years.

Be it ordained by the City Council of the city of Columbus, Ohio, as follows, to-wit:

SECTION 1. That any natural gas company or companies which now have the right to lay and maintain pipes and mains in the streets, avenues, alleys and public grounds of said city for the purpose of carrying and distributing natural gas for private and public use in said city, shall, for the period of ten years from and after passage of this ordinance, be entitled to charge for such gas furnished to public and private consumers thereof, the sum of thirty-five cents per thousand cubic feet, from which price a discount shall be made upon all bills paid on or before the 10th day of each month for gas consumed during the preceding month at the rate of 15 cents per thousand cubic feet during the first and second years, and at the rate of 10 cents per thousand cubic feet during the third and fourth years, and at the rate of 5 cents per thousand cubic feet during the fifth, sixth, seventh, eighth, ninth and tenth years from and after the passage of this ordinance.

SEC. 2. That if any such company or companies shall be unable at any time within ten years from the passage of this ordinance to so continue to furnish natural gas for fuel by reason of insufficient quantity to supply the demand thereof, and shall devise or construct a system or means for furnishing fuel gas, such company or companies shall be entitled, during a period of ten years from the passage of this ordinance, to charge for all such fuel gas furnished for fuel purposes, a sum not to exceed 60 cents per thousand cubic feet, from which price a discount of 10 cents per thousand cubic feet shall be made upon all bills paid on or before the 10th day of each month for gas furnished during the preceding month. Provided, however, that if there should be a difference of opinion between said city council and the company so furnishing natural gas as to whether such company at any time within ten years from the passage of this ordinance is unable to continue to furnish natural gas, by reason of insufficient quantity to supply the demand therefor, the question of whether there is a sufficient quantity shall be determined by arbitrators, one to be selected by said City Council and one by such company, which two shall select a third arbitrator, and the action and award of a majority of such arbitrators as to there being such sufficient quantity, shall be final and binding on all parties.

SEC. 3. When said gas company or companies shall file with the city clerk its or their assent in writing to the terms of this ordinance, the said ordinance and acceptance shall be treated and deemed as a compliance with law for the company or companies so accepting, provided nothing shall be construed as granting to existing companies exclusive rights or privileges, or prevent any other natural gas company or companies from furnishing natural gas to the citizens of said city.

SEC. 4. That said company or companies by accepting the terms of this ordinance shall consent and agree not to sell natural gas or furnish to be sold to any other city or town, or supply the same with gas except those now being supplied by the companies now furnishing gas in the city of Columbus, until all demands for gas in the city of Columbus are supplied, at the prices herein provided even though a higher price may be offered for said gas by some other city or town; and said company or companies shall be permitted to sell to other cities or towns only such gas as it or they may have in excess of that which is demanded for the city of Columbus.

SEC. 5. This ordinance shall take effect and be in force upon its passage and publication according to law.

Passed July 1, 1901.

JAMES J. THOMAS,
President of the City Council.

Approved by the mayor, July 6, 1901.

Attest: JOHN T. BARR, City Clerk.

When the company first began supplying Columbus with gas, about January 1, 1890, it furnished the fuel to factories as well as to residences. By the following November the pressure in the field had so diminished that it was necessary to disconnect the factories, and so base a use of the fuel has not since been made except during the summers of 1899 and 1900. This has greatly prolonged the supply, for which the citizens of Columbus are indebted to the management of the company. In the autumn of 1902 the lines were supplying about 66,000 fires. Mr. J. O. Johnson; superinten-

dent of the company, estimates that during the past five years his corporation has taken on the average 6,500,000 cubic feet of gas per day from the territory.

The Ohio Fuel Supply Company.—The Great Southern Oil and Gas Company entered the Sugar Grove field in 1897, its purpose being to supply Zanesville and intermediate points with gaseous fuel. It is popularly known as the Zanesville company. On May 1, 1902, the corporation transferred its entire property to the Ohio Fuel Supply Company. Besides Zanesville the following places are supplied—Bremen, Rushville, Somerset, Roseville and Crooksville. It is scarcely necessary to state that by far the greater portion of gas is consumed in Zanesville where the following factories are supplied:

National Biscuit Company, gas for heating ovens;
Schultz & Company (Soap works), gas for boilers;
Zanesville Art Pottery Company, gas for kilns and boilers;
S. A. Weller, Pottery, gas for kilns and boilers;
L. K. Brown, Brick and Clay Works, gas for gas engine;
Roseville Pottery Company, gas for kilns and boilers;
Eastern Tube Company, gas for furnaces;
Faience Pottery Company, gas for kilns and boilers;
Zanesville Stoneware Company, gas for kilns and boilers;
Mosaic Tile Company, gas for kilns and boilers;
Ohio Pottery Company, gas for kilns and boilers;
J. B. Owens, gas for kilns and boilers;
G. W. Karns, gas for glass making;
Muskingum Valley Steel Company, gas for boilers and furnaces;
American Encaustic Tile Company, gas for kilns and boilers;
Brown Manufacturing Company, gas for welding and general purposes;
American Chain Company, gas for furnaces and boilers;
Kearns Gorsuch Glass Company, gas used throughout plant;
C. W. Stine Pottery Company, gas throughout plant.

In addition to these establishments the company supplies gas to a large number of residences, offices, stores, etc. In the summer and fall of 1902 the company laid an eight inch line to the Homer field and began using gas from that territory November 19th. The net rates reported are 20 cents per thousand cubic feet for domestic purposes and 12 cents for factories.

Before connection was made with the Homer field the company was not able to supply fully all the factories named, and it is very doubtful if the new field will long provide an ample quantity. In the territory around Sugar Grove the company had 17 producing wells in September, 1902. Early in the year just named the organization constructed a pump-

ing station, and since that time powerful compressors have assisted in keeping the line well filled. The power is furnished by two engines, each of 500 horse power. A pressure of from 150 to 180 pounds per square inch is kept on the line.

The Logan Natural Gas and Fuel Company.—This company was organized with a capital stock of \$40,000 in 1894. The first line was laid to Logan, and in fact the original object of the company was to supply that town only. Finding the supply of fuel larger than the demand a line was laid to the Boys Industrial School, and later this was extended to Laurelville, Adelphi and Chillicothe. The corporation's business has grown rapidly, and by 1903 it was supplying the following places in addition to those already mentioned; Nelsonville, Athens, Newark, Mt. Vernon, Utica, Granville, Thornville, Millersport, Westerville, Cardington, Delaware, Ashland, Bucyrus, Upper Sandusky, Carey, Fostoria, Tiffin, Mt. Gilead, Marion, Galion, Crestline, Mansfield, Shelby, Chicago Junction, Norwalk, Bellevue and Clyde. Quite recently it has secured some sort of control over the Buckeye Company which supplies Circleville. In addition to all this territory the company is endeavoring to extend its lines, and by the time this article is in type the list of cities will in all probability be extended.

The first well drilled by the Logan Natural Gas and Fuel Company was completed in June, 1894. Four years later the property passed into the hands of an organization headed by T. N. Barnsdale. At that time the company had only six producing wells. In September, 1902, the number had grown to 80, exclusive of those in the Homer field. The estimated average open flow of these was 500,000 cubic feet per day. The Buckeye Company, which, as has already been stated, is under the control of the Logan, has drilled 16 wells, all of which were still producing in September 1902. With the decrease in the rock pressure the company has found it necessary to resort to artificial pressure, and accordingly in 1902 erected a pumping station. The power consists of one 600 horse-power Westinghouse engine and one 450 horse-power Kline engine. Each engine operates two compressors, one set having dimensions of $11\frac{1}{2} \times 36$ inches, and the other 14×36 . The cost of the plant was estimated at about \$125,000. The company is making every effort to maintain its supply of fuel and for this purpose keeps several strings of tools at work. When gas was discovered in the Homer field, attention was directed that way, with the result that by September, 1902, the company had 20 wells completed and nine drilling.

The Ohio Transportation Company.—This is a popular name for an organization whose title is the Central Contract and Finance Company. It is also frequently called the Springfield Company. The corporation entered the Sugar Grove field in 1897, laying a 10 inch line to Springfield, a distance of over 80 miles. During some years previous to the date

just mentioned The Miami Valley Gas and Fuel Company had supplied Dayton, Springfield and other places with fuel from the Mercer county field. When this territory failed the company connected its lines with that of the Ohio Fuel Supply Company. In this manner the latter organization has been able to dispose of its gas by simply laying a line to Springfield. The cities and towns in this part of the State supplied with gas from the Sugar Grove field are the following; Dayton, Springfield, Urbana, Piqua, Troy, Sidney, Mt. Sterling, and several small intermediate places. By the spring of 1900 the closed pressure of the wells had so decreased that it was necessary to resort to artificial pressure, and accordingly a pumping station was constructed. The power is furnished by five engines, each of 250 horse power. In 1902 a second pumping station was constructed at Mt. Sterling nearly midway between Sugar Grove and Springfield. The average pressure reported on the line is 250 pounds per square inch. On September 1, 1902, the company had 52 producing wells. The average open flow of these on March 1st preceding was 1,087,000 cubic feet in 24 hours, and an estimated average daily production of 850,000 cubic feet six months later. Of the latter it was thought that only 250,000 cubic feet were available. During the summer of 1902 about 15,000,000 cubic feet of gas were pumped daily from the territory by this company, and it was thought that the quantity would not change materially during the ensuing winter. In cold weather the principal use made of the gas is for domestic purposes, but in summer months a number of factories are supplied. In this manner the shipment of fuel is kept fairly constant. The supply is maintained only by drilling new wells and using powerful compressors. On September 1, 1902, the company had drilled all told about 90 wells, of these perhaps 20 had been abandoned, and approximately 13 were dry when drilled.

The Northwestern Ohio Gas Company.—This corporation is unique in that it operates no wells, purchasing its gas directly from another company or companies. It has a ten inch line running directly to Toledo, a distance of 161 miles. In September, 1901, the company began constructing and soon had in operation two gas engines each of 1,000 horse power, and a year later erected a third engine of similar character and strength. These suffice to keep a pressure ranging from 125 to 200 pounds on the line. This company is said to be the property of The Standard Oil Company, and that the line will be connected with the great 16 inch one now being laid from West Virginia to Sugar Grove. In the fall of 1902 the company was pumping an average of perhaps 8,000,000 cubic feet of gas per day.

The Federal Gas and Fuel Company.—This company was incorporated in 1898. Through action of the legislature, it secured control for gas purposes, of the canal between Lancaster and a point about two miles south of Rock Bridge, Hocking county. This extended through

the heart of the Sugar Grove field, but the territory adjacent to the canal had in the main seen several years use before the Federal company was organized.

The company desired Columbus as a market for its fuel, but naturally the Central Ohio Natural Gas and Fuel Company opposed this. The result was a strong fight in the council at Columbus over a proposition giving the Federal Gas and Fuel Company the right to pipe the streets. However the company won, but only on the condition that it supply fuel at not more than 15 cents per thousand cubic feet. A twelve inch line was laid to the city, and consequently many citizens were supplied who before had been unable to secure natural gas. The company supplies Canal Winchester and Logan also, the rate being 20 cents per thousand.

By November, 1902, this company had drilled over 30 wells. Of these 20 were producing at that time, and a half dozen had been abandoned. The others were failures. Fifteen of the 20 producers just referred to were located in the old canal bed. The others were in Good Hope and Berne townships where the company had secured leases. Additional wells were being drilled, and doubtless the number of producers is now correspondingly larger. Since the wells of this company have been drilled in territory from which a large part of the gas had previously been taken, it follows that the life of the wells will be brief. No pumping station has yet been erected. In April, 1903, the property of this company passed into the hands of the Ohio Fuel Supply Company.

The Cole Glass Factory and Other Companies Using Gas.—The first named organization located at Lancaster has drilled ten wells, six of which are producers. The average daily consumption of gas by this factory when running, as reported by Mr. C. P. Cole, is 1,000,000 cubic feet. All wells are located in Berne township.

The Ohio Flint Glass Factory, also situated in Lancaster, has drilled six wells, all in Berne township. Five of the number were producers, but one of these has been abandoned. The superintendent of the plant, Mr. L. P. Martin, reports that it consumes when in operation about 1,000,000 cubic feet of gas per 24 hours. Besides the two factories just named there are two or three others which have in part an independent supply.

THE HOMER FIELD.

The first well in the Homer field was drilled in July, 1900, and is reported to have begun producing 1,000,000 cubic feet of gas per day. Other wells were soon drilled with similar results. Later, better producers were secured, and in 1902 development was very active. Few dry holes were drilled, and the production started ordinarily at from 1,000,000 to 4,000,000 cubic feet per well; the closed or rock pressure varying from 700 to 800 pounds per square inch.

Early in the fall of 1902 a well was completed on the Hunter farm near the middle of section 6 of Miller township, Knox county. According to reliable reports this had an initial open flow of between 11,000,000 and 12,000,000 cubic feet per day. In December following a well was completed on the Miller farm located in the northern part of the same section, and a 9,000,000 cubic foot producer secured. Early in January, 1903, a well was drilled on the Beinhower farm in the southwest corner of the same section, the result being an open flow at the rate of 11,000,000 cubic feet per 24 hours.¹ While these wells were being drilled a number of producers ranging in size from 4,000,000 to 6,000,000 cubic feet were secured farther north. This is by far the richest portion of the Homer field, and radically changes the character of the territory.

It appears from what has just been stated that the size of the maximum wells in this field equals those of Sugar Grove; the average of those of Homer, however, is much smaller. Time has not been sufficient to test the lasting quality of the wells in the new field, but the indications are that it will compare favorably with the excellent territory farther south.

Strenuous efforts are being made to extend the limits of the producing territory. A small well has been secured in the northwest corner of Clay township, Knox county, and one on the Taylor farm in the northern part of Union township, Licking county. The latter well, according to information furnished by Professor Thomas L. Watson, had an initial open flow of 2,000,000 cubic feet per day, and a closed or rock pressure of 800 pounds per square inch. Both wells lie outside of what is known as the Homer field.

Several of the largest companies operating in the Sugar Grove field have entered this territory, and are piping gas to Columbus, Zanesville and other places. Doubtless in the near future fuel from the Homer field will be consumed in many cities in northern Ohio. This much can be said for the territory at present,—the acreage is large, rock pressure high, and gas rock continuous.

GEOLOGY OF THE FIELD.

Succession of Strata.—This is shown by the following records: Well No. 1 of the Federal Gas and Fuel Company, located in the canal bed four miles below Lancaster. Completed April 28, 1899.

Character of Formation.	Thickness of formation. Feet.	Depth to bottom of formation. Feet.
Drive pipe	54	54
Shale	91	145
White sand, charged with water.....	20	165
Sandy shale	135	300
Gray shale	90	390

¹Data furnished by J. O. Johnson, Supt. Central Ohio Nat. Gas and Fuel Co.

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Character of Formation.	Thickness of formation. Feet.	Depth to bottom of formation. Feet.
Sunbury (Berea) shale.....	52	442
Berea sand	25	467
Cased with 8¼ inch casing.		
Red shale (Bedford).....	103	570
Black shale (Ohio).....	560	1,130
White shale (Ohio).....	142	1,272
Top of lime (Corniferous) at.....		1,272
First water in lime at.....		1,407
Second water; rose to top of well.....		1,682
Cased with 6¾ inch at.....		1,944
Bottom of Niagara limestone at.....		1,959
White slate	66	2,025
Red rock (shales).....	18	2,043
Limestone shell	8	2,051
Blue slate	4	2,055
Shells	15	2,070
Blue slate	5	2,075
Clinton sand, top.....		2,075
Total depth		2,088

Below is given a record of the lower part of the Bauer well located on section 5 of Berne township. Samples of the drillings were collected by the writer.

	Feet.
Bottom of the Niagara limestone at.....	2,132
Shales, light chocolate color; some lime.....	2,132-2,168
Shales, green and chocolate colored, the latter fossiliferous; some lime.....	2,168-2,199
Shales, green and chocolate colored; much lime.	2,199-2,236
Clinton sand at.....	2,236

For comparison there is given next the record of the deep well drilled on the Kockensberger farm about 20 miles east of Lancaster, near Junction City. This well was begun in March, 1900, and completed two years later:

Character of Formation.	Thickness of formation. Feet.	Depth to bottom of formation. Feet.
Drift	15	15
Blue clay, top at.....	15	30
White sand	75	105
40 ft. 8¼ in. casing.		
Blue slate	15	120
Gray sand	20	140
White sand	30	170
Slate and shells.....	50	220
Black shale	30	250
White slate (Cuyahoga)....	300	550
Brown slate (Cuyahoga)....	235	785
Sunbury (Berea) shale.....	41	826
Berea sand (steel line meas- urement).....	14	886
White slate and red rock.....	14	900
910 ft. of 6¾ in. casing.		

Character of Formation.		Thickness of formation. Feet.	Depth to bot- tom of for- mation. Feet.
Ohio shales.....	Black slate	60	960
	White slate	355	1,315
	Brown slate	295	1,610
	White slate	110	1,720
	Brown slate	15	1,735
	White slate	165	1,900
	Slate	160	2,060
Corniferous, Lower Helder- berg and Niag- ara	Top of Corniferous lime- stone at.....		2,060
	Break in limestone at..		2,500
	Bottom of break at.....		2,560
	Bottom of limestone at..		2,950
	2,810 feet of 5 3-16 inch casing.		
Clinton.....	Red rock	40	2,990
	Blue slate	95	3,085
	Clinton sand stone at.....		3,085
	Bottom of well, still in Clinton		3,100

The most interesting point about this section relates to the Ohio shales. These were struck at a depth of 900 feet, and the bottom was reached at 2,060 feet, showing a thickness of 1,160 feet for the formation. The record of the Federal well near Lancaster gives these shales a thickness of 702 feet. This is an increase of 458 feet in about 20 miles, or 23 feet to the mile. The great limestones have a thickness in the Federal well of 687 feet, and this is about the average for the entire Sugar Grove field. In the Junction City well the thickness found is 890 feet, an increase of 203 feet or about ten to the mile. The deep well drilled at McConnellsville found the Ohio shales 1,712 feet thick.¹ This point is 42 miles east of the Federal well; hence the increase in thickness of the Ohio shales averages 24 feet to the mile. If this rate of increase continues eastward to the Ohio river the formation would reach 3,000 feet in thickness. This corresponds with what has already been demonstrated in Columbiana county. The importance of this feature in our geology cannot be over-estimated by the seeker for oil or gas. It demonstrates the folly of attempting to make the Clinton or Trenton formation a source of oil or gas in a commercial way in eastern Ohio.

The following skeleton record of the McNichols well, twenty-five miles south of Sugar Grove in Jackson township, Vinton county, is of interest because it shows the thickness of both the Clinton and the Medina:

¹It will be noted that these figures do not agree with those given on the accompanying diagram. The difference results from the Ohio shales alone being considered in the text, while in the diagram both the Bedford and Ohio shales are included.

	Feet.
Berea grit, top at.....	888
bottom at	942
730 feet of 8 1-3 inch casing.	
942 feet of 6¼ inch casing.	
Corniferous Lower Helderberg and Niagara limestones,	
top at	1,735
bottom at	2,390
Clinton, top at.....	2,390
bottom at	2,460
Medina, hard above, but very soft below, top at....	2,460
bottom at	2,560
2,554 feet of 5 3-16 inch casing.	
Cincinnati series, top at.....	2,560
bottom of well.....	2,860

Lastly there is given a skeleton record of a well near Homer, in the northern part of the Central Ohio Natural Gas Fields. The location is on the Beatty farm in Burlington township, Licking county :

	Feet.
Drive pipe.....	160
Bottom of Berea (cased here).....	618
Top of limestone (Corniferous).....	1,420
Bottom of limestone (Niagara).....	2,100
Top of Clinton sand.....	2,303
Bottom of Clinton sand.....	2,315
Top of Medina shales.....	2,340
Total depth.....	2,345

This makes the interval between the Berea grit and the Ohio shales 802 feet, and the thickness of the limestone 680 feet. Other wells drilled in different parts of the field make the interval referred to vary from 754 to 826 feet, and the thickness of the limestone range from 680 to 764 feet. An average of 7 measurements gives 743 feet. This is nearly 50 feet greater than the average in the Sugar Grove field.

The Clinton Formation.—The only part of Ohio in which the Clinton outcrops is the southwestern. Its area there is very small, but it is usually conspicuous. This results from the fact that the underlying rocks are shales; while the Clinton, being composed of much more durable material, forms an escarpment. The formation is composed essentially of limestone. This is highly crystalline, delicately colored, and quite fossiliferous. It takes a good polish and has been called marble. At places it is a building stone of high grade, but the lenticular nature of the bedding is an obstacle to its use for this purpose. In composition the limestone is calcareous, and in places it becomes the purest rock of this type in Ohio. The following is an analysis from near Osborn, Green county:¹

¹*Geol. Sur. of Ohio*, Vol. VI, p. 728.

	Per cent.
Carbonate of lime.....	97.14
Carbonate of magnesia.....	1.21
Alumina and oxide of iron.....	.41
Silicious matter	.70
	99.46

Occasionally there is found a thin bed of clay, called by Foerste the Beavertown marl, overlying the limestone, and at other places a lean deposit of the Clinton ore. The latter furnished the iron for one of the pioneer blast furnaces of the state.

That the Clinton limestone along its line of outcrop contains petroleum has long been known. This character appears to have been reported for the first time by Dr. John Locke in 1838.¹ Orton made similar observations in 1878, 1886² and 1888.³ Neither of these geologists, however, suspected from the surface exposure that the formation might contain either oil or gas in quantities sufficiently large to be of service to man. When the Trenton was being tested at Fremont it was noticed that considerable gas escaped from the Clinton, and the former horizon proving barren a number of wells were drilled to the latter, the supply of gas secured being sufficient usually for one or more residences.⁴ These were the first wells drilled anywhere in Ohio for the purpose of securing gas from the Clinton. The formation in the northwestern part of the state consists of limestone with a small amount of shale. The general relations are shown in the following record of a well at Fremont:⁵

	Feet.
Waterlime	160
Niagara limestone.....	200
Niagara shale (thin).....	
Clinton limestone.....	105
Medina shale.....	105
Cincinnati (Hudson River) shale.....	450
Utica shale.....	308
Trenton limestone at.....	1,328

In central Ohio the formation presents a complete change. The limestone has disappeared and there is found in its place a body of shales and generally an intercalated bed of sandstone. As shown in the well records already given these shales have colors ranging from green to brown. They contain a noticeable amount of carbonate of lime which becomes most abundant in the 35 feet above the gas rock. The drillings strongly indicate that the green and chocolate colored shales are inter-

¹*Geol. Sur. of Ohio, Sec. An. Rept.* (1838), p. 225.

²*Ibid.*, Preliminary Rept. on Oil and Gas (1886).

⁴*Ibid.*, Vol. VI, p. 187-8.

³*Ibid.*, Vol. VI, p. 12.

⁵*Ibid.*, Vol. VI, p. 112.

stratified with the calcareous ones. The gas rock is a light colored sandstone of moderate fineness. In the northern part of the territory the rock has less color and also fewer impurities than it has in the Sugar Grove field—if the testimony of experienced drillers can be relied upon. Farther south in Vinton county the sand has a decided brown color. The rock drills hard, suggesting that the grains of sand are well cemented together. It has not been customary around Sugar Grove to drill through the gas rock, and hence data bearing on its thickness are not abundant. The maximum reported is 34 feet, and the average is perhaps a little more than one-half of that. In the northern part of the field, that is around Homer, the sand is drilled through. Five wells selected at random show thicknesses of 10, 28, 8, 12 and 18 feet, an average of 15.

Below the gas sand is found a bed of shales commonly ranging from 10 to 35 feet in thickness. This has a dark color, and is succeeded below by red shales. Since work usually stops before the latter are reached, or when they have been penetrated a few feet, thus making certain that the position of the gas sand has been passed, data bearing on the thickness of these shales are meager. The McNichols well, a log of which has already been given, credits 100 feet to the formation. The top of this red rock is regarded as the summit of the Medina.

Rock Structure.—The strata in the Sugar Grove field have been considered by some on *a priori* grounds to form an anticline, and by others a terrace. Neither, however, appears to be correct. On a line running about due east and west through Sugar Grove, the rock dips to the east nearly 260 feet in less than six miles, barometer measurement, an average of 45 feet per mile. This shows neither arch nor terrace extending through the territory north and south. Further at the village Amanda, 11 miles west of Sugar Grove, the Clinton rock lies 600 feet higher than it does at the village last named. This makes improbable the suggestion that the gas belt may lie on the eastern slope of an arch, as several reservoirs of oil and gas are known to do in eastern Ohio.

From Lancaster the rock dips southeast more rapidly than the bed of the Hocking river slopes, as is shown by the increasing depths of the wells in the valley of this stream. This excludes the idea of an east and west arch or terrace.

Size of the Wells.—The closed or rock pressure in the Sugar Grove field was originally about 700 pounds per square inch. At present it varies much. Thus at Lancaster, where the first wells were drilled, the pressure has fallen so low that with one exception all wells have been abandoned, while a mile or two farther north in the southern part of Pleasant township the pressure is still from 500 to 600 pounds. Near Sugar Grove the pressure (September 1, 1902) was less than 200 pounds, in some wells only one-half of that, but farther away from the village it is greater. Thus a well drilled in the fall of 1902 on the Brandon farm,

five miles north of Sugar Grove, showed a rock pressure of 400 pounds, and one on section 2 of Laurel township, Hocking county, drilled in December, 1901, recorded 700 pounds and nine months later 650 pounds per square inch. These variations indicate that the field does not consist of one vast reservoir, but of several small disconnected areas. These are separated either by the sandstone disappearing or more probably by the rock becoming so compact in places that it cannot act as a reservoir for the gas.

The open flow of the wells has varied greatly. Thus wells early drilled in the vicinity of Lancaster have ranged from almost nothing to 12,000,000 cubic feet per day. Among the largest reported are the following: One in Laurel township, Hocking county, 9,500,000 cubic feet; one on the Hummel tract in Berne township, Fairfield county, 10,000,000 cubic feet; the Mithoff well in Lancaster, 12,000,000 cubic feet. These figures, of course, refer to the initial open flow.

As has already been stated the initial closed pressure in the Homer field ranged from 700 to 800 pounds per square inch, and the open from 1,000,000 or less to more than 11,000,000 cubic feet in 24 hours. Data concerning the wells in the Newark and Thurston fields have already been given, and it is seen that the initial closed or rock pressure of the entire central Ohio fields has ranged from 700 to 800 pounds per square inch, and that the largest well had an open flow approximating 12,000,000 cubic feet per day. A number of experiments have been made by torpedoing the wells, but the results have not been satisfactory.

Life of Wells.—This depends on several factors; such as nature of gas rock, closed pressure, initial flow, proximity of other wells, rapidity with which gas is used, care taken of wells, presence or absence of salt water in the gas rock, etc. A small number of wells drilled ten years ago are still producing, but such records are unusual. The short life of the Thurston field has already been noted. The Homer field is too young to have demonstrated its lasting qualities. The following records in the Sugar Grove field show the decline in rock pressure and open flow of the wells in that territory. These are wells that have been in almost continuous use. Of course where the wells are closed in during a large part of the year the decrease is much slower than the records previously given indicate. This point is well illustrated in the wells north of Lancaster, which were drilled about ten years ago, but still have a closed pressure of from 500 to 600 pounds per square inch. As has already been stated the company is holding them in reserve until the wells in other parts of the field are inadequate to meet the demands. The table shows very clearly the brief life of the wells. Since the rock pressure is decreasing it follows that wells drilled hereafter will be exhausted even more rapidly than those given below.

Table Showing the Initial Rock Pressure and Open Flow, and the Decrease of these in Wells of the Sugar Grove Field.

Name of Well.	Rock pressure, pounds per square inch.	Open flow per 24 hours, cubic feet.	Rock pressure, April 1, 1901.	Open flow, April 1, 1901.	Rock pressure, Sept. 1, 1902.	Thickness of sand, feet.	When abandoned.
Berry No. 1	785	7,161,000	.0	0	.0	18+	July, 1899.
Conrad No. 1.....	900	4,570,350	190	2,260,000	.0	14+	Nov. 18, 1901.
Blazer No. 1.....	740	9,000,000	170	3,500,000	.0	...?	Feb. 4, 1902.
Berry No. 2.....	740	7,151,500	150	1,746,000	.0	13+	June 5, 1901.
Lutz No. 1.....	890	3,212,500	230	2,254,300	170	...?	Still prod. Sept., 1902.
Kestler No. 2.....	500	8,758,000	240	?	120	15+	" " "
Ream No. 1	790	7,163,000	205	3,162,800	125	7+	" " "
Harman No. 1 ...	650	9,969,000	220	?	..?	...?	" " "
Wooden No. 1 ...	700	8,374,000	.0	0	.0	18+	Abandoned Feb., 1901.
Shull No. 1.....	640	8,870,500	300	5,530,000	150	18+	Still prod. Sept., 1902.
Edwards No. 4...	410	3,000,000	230	?	175	20+	" " "
Kesler No. 1.....	800	6,451,000	225	3,571,800	100	13+	" " "
Starner No. 1.....	420	7,500,000	..?	?	120	24	" " "
Brandan No. 1...	425	2,000,000	..?	?	250	19	" " "
Dupler No. 1	580	7,128,000	..?	?	210	26	" " "

Care of Wells.—Care is required with reference to two points; (1) water, (2) salt, the former being by far the most troublesome. Both are derived from the great limestone lying above the Clinton formation, and if it were possible to prevent the salt-water from reaching the gas sand no trouble would be experienced from either.

When the closed pressure is large the water is driven from the gas rock by simply opening the well at the top, and allowing the gas to drive the water from the well; but when the pressure has become small, as it will be in all cases sooner or later, the force of the gas may not be sufficient to lift a column of water filling a two inch tube. In such cases an inch tube is inserted inside the two inch, and the pressure of the field turned into the large one, thus forcing the water through the smaller tube.

The frequency with which wells require blowing varies with the nature of the well. Some require attention twice a day; others twice a week; others once a week, etc. The time required to clean the well varies greatly, increasing with the quantity of water to be removed and the decrease of the rock pressure. Perhaps the average time in the Sugar Grove field in 1902 was 15 or 20 minutes.

Trouble from salt arises in one of two ways, either by accumulating in the gas rock, or around the end of the tubing, and so shutting off the flow of gas. This is removed by first pouring water into the well, and thus dissolving the salt, and then blowing the brine out by the method already explained. In obstinate cases vinegar is used in place of water.

Composition of the Gas.—Below is given an analysis of gas from the Thurston field, the work having been done by Professor C. C. Howard of Starling Medical College:

	Per cent.
Carbon dioxide	.25
Oxygen	.15
Olefines	.30
Carbon monoxide	.15
Nitrogen	8.12
Hydrogen	.55
Paraffines (Marsh gas, etc.)	90.48

For comparison there is given an analysis, made by the same chemist, of natural gas from the Trenton limestone at Findlay.

	Per cent.
Marsh gas	92.61
Olefiant gas	.30
Hydrogen	2.18
Nitrogen	3.61
Oxygen	.34
Carbonic acid	.26
Carbonic oxide	.50
Sulphureted hydrogen	.20

CHAPTER IV.

THE CARBONIFEROUS ROCKS AS A SOURCE OF OIL AND GAS.

These rocks are found at the surface of the eastern half of the state, but the important reservoirs of oil and gas are restricted to the areas where the coal measures constitute the surface formations. The producing strata have a great range stratigraphically, the lowest being the Berea grit, while the highest lie in the Monongahela formation or Upper Productive Coal Measures. These sands and their relative positions are shown in Chapter I. As will be seen from what follows this was the first territory developed in the state, but it is now greatly surpassed in production by the Trenton limestone.

OIL AND GAS IN MORGAN COUNTY.

Two pools of oil and one reservoir of gas have been discovered in this county:

1. The Chester Hill oil field;
2. The Buck Run oil field;
3. The McConnellsville gas field.

With the exception of the last named, the producing sand is the First Cow Run. From this it follows that the wells are shallow, and hence the expense of drilling comparatively small. The territory has contributed much to the wealth of the county. The Chester Hill pool is one of the important ones in the state. It extends into Athens county on the south and Washington on the east, but for convenience will all be considered under the head of Morgan.

THE CHESTER HILL OIL FIELD.

Location and Area.—The oldest part of this field lies one-half mile north of the village Joy in Homer township, Morgan county. The land is known as the Dale and Boileau farms, and occupies section 2 and the south half of section 3. From this the productive strip runs south through section 1, and then entering Ames township, Athens county, passes southwest through sections 16, 12, 11 and 17. Starting again with the Dale farm and going east the productive strip extends almost to Chester Hill when it turns abruptly to the southeast, continuing in that direction for 3 miles and then curving again to the northeast it passes through sections 7, 1, 8, 2 and 3. From this locality it enters Wesley township, Washing-

ton county, where it follows the valley of Wolf creek almost continuously as far east as Brown's Mills, and then bears off to the southeast for a distance of 3 miles. The length of this strip is nearly 25 miles. Nowhere has it a width exceeding one mile, and in some places there is room for a single row only of wells. Notwithstanding the fact that it lies in three counties, it will, since it forms a continuous pool, be considered wholly in this place.

Discovery and Development.—The residents of the fertile valley of Federal creek just north of Joy recognized "surface indications" of oil from the time of settlement of the territory. An oily substance was sometimes seen floating on the water of the creek, and when a hole was dug in the valley oil would sometimes gather in it. It was not until 1860, however, that a well was sunk in search of the strange smelling substance which found its way to the surface. The pioneer well is said to have been drilled by S. S. Teller, of Franklin, Pa., on the Joshua Bishop, now the Boileau farm. At the depth of 65 feet an 8 barrel producer was secured. It produced about 20 years and then was abandoned.

In the summer of 1860 a company was formed at Lancaster, Ohio, with a capital stock of \$1,000,000.¹ It bought the Joy (now Dale) farm of about 400 acres for a sum reported at \$375,000, and in the winter of 1860-61 began drilling directly across from the Boileau well, securing a 20 barrel producer. These wells caused great excitement, and the narrow valley was filled with speculators. The land was divided into small tracts, sometimes a quarter of an acre on which two or three wells might be drilled. These patches sold for extravagant amounts; thus for one-half an acre, on the Bishop farm, on which there was a ten barrel well, \$10,000 were paid.

During the summer of 1861 probably 25 wells were completed or being drilled in the field, and it is estimated by an operator who resided in the territory at that time that 50 men were working on the Boileau and 100 on the Joy farms. The valley was dotted with wells, most of which have been abandoned, and the very location of many forgotten. The dry holes and the wells which had ceased to be profitable were filled with sand hauled from the creek to prevent the water from reaching the oil rock, and this helped to obliterate many of the early locations. From what has been said it is apparent that the two tracts most prominent in the early development of the field were the Bishop and Joy farms, and the early history of the territory is simply the record of these two places.

The Bishop farm consisted of 325 acres, and in the early sixties sold for the munificent sum of \$100,000. Doubtless when the speculative era was at its highest, and this property was divided into small lots, it commanded a much larger figure. A number of the wells drilled during the civil war are still producing. Thus one located in the northwest corner of

¹These figures are reports. No records are obtainable.

the place, and drilled probably in 1861, with a depth between 70 and 80 feet, has been yielding oil during the greater part of the past 40 years. It was never shot until 1897, and in 1900 was producing less than one barrel per day. Another of these pioneers stands a few hundred feet south of the last well, on the north bank of Federal creek. It was drilled in 1862 probably, is 72 feet deep, and is reported to have started at from 30 to 40 barrels per day. It had not produced long, however, until there was a heavy drop in the price of oil, and the well was closed until about 1880, when it was operated for a short time, and then again closed until 1892. Not until 1898 was it shot, and then with only ten quarts. Other wells in the valley date back to the civil war, but those on higher land were drilled within the past few years. The pioneer drillers here as elsewhere regarded the productive territory limited to the valleys. The old wells when first drilled usually produced sufficient gas to force the oil to the surface, sometimes to throw it to the top of the derrick; but at present the gas pressure is so small that the wells all have to be pumped.

The Joy farm, as has already been stated, was sold in 1860 for \$375,000. The company worked assiduously and soon secured a number of producers, some of which are still being pumped. Well No. 4 was one of the first in the valley. The bottom of the Cow Run sand was found at 85 feet, and the Cambridge lime was struck at 92 feet. It still (1900) produces 4 barrels every 12 hours, but to secure this, 400 barrels of salt water have to be pumped. Another of the interesting wells is No. 2, which was drilled between 1861-63, and at first was thought dry, and so abandoned. Two years later it changed hands, was cleaned and put to pumping, and began producing 10 barrels daily. About 1870 the Mansfield Petroleum Company secured the lease, and shooting the well with a quart of nitro-glycerine, was rewarded with a production of 80 barrels per day. From that time it has produced continually, but its production has gradually diminished. In 1897 it was estimated that the well had yielded \$120,000 worth of oil.

The Joy farm has changed owners a number of times since 1860. The first company, though it paid a large sum for the property, seems to have fared very well. Of the \$1,000,000 capital stock it is said that \$500,000 was sold at par in New York, and the remaining half advanced 50 per cent. in price and then one-half of it sold to New York parties. The Mansfield Petroleum Company sold out to Dale for \$26,000 at a time when there were only two producing wells. Later the new owner having become discouraged, made complaint to the Mansfield Company, which reduced the price it was to receive by \$4,000. Dale operated the property under the name Midland Oil Company, and began drilling wells as soon as he came in possession of the property, but did not secure a large production until 1893-94, which period marks the beginning of the modern history of the field. Later Dale leased to Haskell & Liken, but afterwards



bought their lease and then leased it to the present operators, Reusen, Shedd & Company, receiving \$80,000, the company taking possession March 22, 1900.

When the field was being opened much of the oil was hauled in barrels to McConnellsville and Stockport, but the greater part was taken to Big Run and from there shipped by rail to Marietta. About 12 years ago Dale laid a pipe line to Sharpsburg, from which point the oil was transported in tank cars. When the Corning pipe-line was laid in 1893 a branch was run to the Joy field, but later as the territory was extended a line was laid direct from Joy to Elba.

The Dale farm is much larger at present than it was when Joy sold it in 1860, and now comprises 965 acres. The present operators are drilling new wells and making improvements in other ways. On July 17, 1900, there were 55 wells pumping, and the daily production during the previous month averaged 107 barrels. The best well on the place at that time was No. 49, which produced 20 barrels every 12 hours. It had an initial production of 40 barrels per day when drilled in August, 1898.

Reusen, Shedd & Company have extended their property by purchasing the Hopkins farm on the south and the Boileau on the east, the two comprising 480 acres. In August, 1902, there were 66 wells on the Dale farm proper, and these were producing 120 barrels per day. The best well secured in recent years produced 85 barrels in 9 hours. The company keeps a string or two of tools at work almost continuously, and within a year will have the farm drilled over. On the Hopkins and Boileau farms the company had 21 producers, the daily production of the 87 wells combined being 143 barrels.

Wells having a daily production of only an eighth of a barrel are now pumped, a condition made profitable by connecting the wells tandem fashion with a gas engine. The latter is of 20 horse-power, and it is claimed could pump 100 wells if they were properly grouped. Sometimes the engine room is not visited except at starting and stopping, but generally some one drops in a time or two during the day to see that all is well. The saving in time and money by this form of power is immense.

A start in the development of the territory lying between the Dale farm and Chester Hill was begun in 1892, when J. A. Lovell leased 40 acres off the northeast corner of the Dale farm and drilled 7 wells, all of which were producers. No pipe-line had been laid in the field yet, however, and the lack of shipping facilities caused Lovell to suspend operations until 1895, when having been joined by H. E. Smith, he drilled 10 wells on the McElfresh farm, but later sold this property to the Cumberland Oil Company. In the fall of 1897 Lovell, in company with H. C. Lord, leased the L. and J. Mozier, Clark Woolman and John Morris farms, on which they drilled 87 wells during the following 2 years. Of this number 76 were producers and only 11 dry holes. In 1899 these farms

became the property of the Cumberland Oil Company. In 1897 P. B. Vore drilled a well on the Hopkins farm, still farther east, and, securing a small producer, sold the lease to the Octo Oil Company, of Pittsburg, which drilled 25 wells on the farm, 20 of which were producers. A year later H. H. Burns, of Mannington, West Virginia, purchased from Swayne and Bailey for \$7,000 the lease on the second J. Mozier farm, and in 1899 drilled 20 wells on the place, 16 of which were producers. These operations seemed to have determined the limits of this part of the field, and the following year was given to the development of the territory confined within these lines, though some effort has been made to extend the productive territory. In 1899 drilling began actively in the territory south of the Dale farm, and has been progressing since that time. In 1902 wells were being sunk west of Federal station on the M. C. & C. railroad. The sand in a valley was found at 53 feet, the interval between the Ames limestone and the oil rock being 65 feet. The wells are small and the sand spotted, so that very little can be expected from this part of the field.

In the spring of 1899 a well was drilled on the land of E. J. Lambert, two miles south of Chester Hill. When put to pumping it started at 60 barrels, but the production decreased so rapidly that the well was abandoned the following December. Within a year 40 wells were drilled in this field, one-half of which were failures. In December, 1900, the Southwest Petroleum Company and A. J. Lovell bought the pool for \$37,000, the production being 37 barrels per day. The first well was drilled on the Crayton farm between two dry holes 400 feet apart, and a 30-barrel producer secured. With this encouragement other wells were drilled in quick succession and the pool was soon connected with the production lying to the northwest and to the northeast.

While the territory west of Chester Hill was being developed the drill was busy in the valley of Wolf creek, east of the village. Oil had been known in this valley for nearly 40 years. A well is reported to have been drilled in 1864-5 along this stream on the Mercer farm, in the northeastern corner of Wesley township, Washington county. It produced for a short time only, but demonstrated the existence of the liquid. However, this discovery was of no pecuniary importance, since further exploration was not made for 35 years. The first of the modern producers was drilled in March, 1899, on the northeast corner of section 2, Marion township, Morgan county. Other wells followed in quick succession, and a small pool was developed which later was connected with the principal strip along the creek.

In the early spring of 1900 Lane & Vanlaw drilled a well in the extreme northwest corner of Wesley township, Washington county, on the H. A. Vanlaw farm, about one-eighth of a mile from the creek. A small producer was secured, and another well was begun. Before the latter

was completed, however, H. H. Burns had drilled on the Russell farm, on the north bank of the creek, securing a well having an initial production estimated at 190 barrels daily. Naturally, Lane & Vanlaw, whose lease extended to the creek, and included land just opposite from Burns', located their next well directly on the bank. The First Cow Run sand was struck at a depth of 287 feet, and the well began to flow at once. At this stage the drill was stopped until more tanks could be secured; they then continued drilling, until the sand, having a thickness of 13 feet, had been passed through. The output of the well increased greatly, having a production of 1,200 barrels the first day, according to the estimate of Mr. Vanlaw, one of the operators. Others, however, have estimated the production as low as 400 barrels. Wells were at once started on both banks, and in every case a good producer was secured, though they were much smaller than the one just described. In July, 1900, 12 drills were at work along the creek in the immediate vicinity of the Vanlaw farm.

About one mile southeast of the last tract another productive strip was discovered in June, 1899. The central part of this was occupied by the Zumbro farms. It was situated principally on hilly territory, a short distance from the creek, though the latter runs directly across the eastern end of the belt. This field, too, was very active in 1900, the principal extension being east of Wolf creek near the place where it is joined by Coal run.

In March, 1900, a producing well was drilled on the Yarnell farm, near Brown's Mills. Two additional wells were drilled in quick succession. On the 6th of June well No. 4 was completed and began producing 1,400 barrels per day. In all 16 producers and 5 dry holes have been drilled on the farm. In May, 1900, the production was 20,000 barrels; in July, 1901, 2,904 barrels; in July, 1902, 1,965 barrels. Naturally, the drill moved out in all directions from this farm, and the limits of the territory were soon determined in all directions except the southeast.

It is seen from what has been said that work in the Chester Hill field began at several points at about the same time. Later work has connected these pools, forming a continuous strip from Federal to a point 3 miles southeast of Brown's Mills. Between the latter and Moore's Junction several small pools have been found, and not improbably these will be connected, forming a continuous strip to the Ohio river.

In the southwestern corner of Windsor township, Morgan county, a small pool of oil was discovered in 1901. It starts near Dale P. O. and runs northwest in a discontinuous manner for nearly two miles, and then due north for another mile. The strip is very narrow, sometimes containing one row only of wells. The producing sand lies just above the Cambridge limestone and so is the First Cow Run. It is decidedly patchy, and appears to be restricted to the producing territory. The best wells started at about 40 barrels and the average at perhaps one-half that

amount. The number of dry holes is nearly as numerous as the producing wells. The southern extremity of the pool lies within one mile of the Chester Hill field proper and the two may eventually be connected.

Three miles northeast of Chester Hill a small pool was discovered in 1899, the first well having been drilled on the land of Samuel Milner. The First Cow Run sand was found at a depth of about 310 feet. It lay about 90 feet below the Ames limestone, but was so thin that it made nothing better than a show of oil. The best well on the place had an initial production of 30 barrels daily, but a year later had decreased to three barrels for a corresponding period. In this well there was a production from two sands,—(1) The First Cow Run, and (2) the Wolf Creek or Milner, which lies about 90 feet above the former. The three wells on this place were producing conjointly four barrels daily, when it was visited in July, 1900. The oil from the tank on the farm had a gravity of 46 B.

About 14 wells have been drilled on the adjacent farms owned by Stephen Milner, Joel Starlin and J. F. Calvert. All went to the Cow Run sand. The producers found were small, the ten wells having a daily production of 12 barrels only, when the locality was visited.

Geology of the Field.—On the Dale farm, near Joy, the Pittsburg or Federal Creek coal lies 180 feet above the valley, while the hill tops extend about 200 feet higher. The Ames or Crinoidal limestone lies just above drainage on this farm, and the interval between it and the Pittsburg coal is 170 feet. Just below the village of Joy this limestone passes under drainage, but appears again farther west near Federal and south near Amesville, Athens county, where it is finely shown in the valley, and where it received its name. It is very persistent and is found in every well in the vicinity of Joy. The formation does not ordinarily exceed 2 feet in thickness. It is filled with fossils, especially crinoid stems, and is very hard, giving a metallic ring when struck by the tools, and so is easily recognized by the driller. These characters make it one of the most important geological landmarks both above and below drainage in the shallow territory of southeastern Ohio. Another well-known limestone in this district is the Cambridge, which is thicker than the Ames but is much less fossiliferous. Lying as it does either immediately below the First Cow Run sand, or separated from it by a few feet only of shales, it serves as a base, which when reached by the driller shows that the position of the oil sand has been passed. Since the strata in this part of the state dip to the southeast, the lime bearing formations under consideration lie farther below the surface in that direction and cannot be satisfactorily located farther east than Brown's Mills. This may be due to the disappearance of the rocks in question; or it may result from the fact that heavier drilling tools are used, which may pass through the thin limestone so rapidly that the driller does not recognize them.¹

¹The Ames limestone is found above drainage in the eastern part of Washington county, where the Newell's run anticline crosses the Ohio river.

Aside from the two limestones and the oil sand, the underground strata are not well marked or conspicuous over a wide area. They are composed of shales and sandstones, the former greatly predominating. One of the best-known of these is a bed of red shales having a thickness near Joy P. O. varying from 15 to 40 feet, and known among the drillers as the "Big red." It lies above the Ames limestone, as shown by logs which follow. Above the "Big red" are found large beds of shales, sandstones, limestones and the Federal creek coal, to which reference has already been made. None of the latter, however, can be traced over an extensive area. The coal seam is lost almost as soon as the driller moves east from the Federal creek valley, while the limestones are not continuous like the Ames or Cambridge.

The succession of strata is shown by the following well records:

Well on farm of Lewis Morris, section 24, Ames township, Athens county. Log furnished by E. M. Woodin:

	Thickness of stratum. Feet.	Total thickness. Feet.
Gravel	10	10
<i>Ames limestone</i>	2	12
White sandstone.....	12	24
Blue shales.....	20	44
Red shales.....	20	64
Blue shales.....	15	79
Red shales.....	5	84
Dark shales.....	10	94
Sandy shale, place of First Cow Run sand..	33	127
<i>Cambridge lime.</i>		

The following is the log of gas well No. 1 on the Dale farm, Homer township, Morgan county, and was furnished the survey by G. A. Faires, Superintendent of the Reusen-Shedd Company. The record is more interesting than most others obtained in this field, since it extends to the Salt sand:

	Thickness of stratum. Feet.	Total thickness. Feet.
Red shales	29	29
Blue shales.....	3	32
Red shales	10	42
Blue shales	30	72
Dark sand	5	77
Dark shales	1	78
Gray sand	9	87
<i>First Cow Run sand</i>	20	107
Soapstone and shales.....	58	165
Coal	2	167
Soapstone and shales.....	15½	182½
Dark sand	3	185½
Soapstone and shales.....	23½	209

	Thickness of stratum. Feet.	Total thickness. Feet.
Black shales	9	218
Gray shales	37	255
Black shales	35	290
Sand rock	36	326
Shales	91	417
Sand rock	26	443
Shales	47	490
Dark sand rock.....	6	496
Shales	6	502
Sand with gas.....	8	510
Shales	2	512
Sand rock	3	515
Dark shales.....	9	524
Light shales	36	560
<i>Salt sand</i>	52	612

Below is the log of a gas well on the same farm. It was drilled in the fall of 1899, and furnishes sufficient gas to run two gas engines, the hotel and one residence.

	Thickness of stratum. Feet.	Total thickness. Feet.
Red shales	40	40
Blue shales	12	52
Red shales	10	62
Yellow shales	17	79
Gray sand	3	82
<i>First Cow Run sand</i>	2	84
Blue shales	6	90
<i>Cambridge limestone</i>	2	92
Dark and light shales.....	178	270
White sand	40	310
Black shales	65	375
Gas sand	9	384

This sand is known locally as the Second Cow Run, but since in the typical locality the interval between the two Cow Run sands is approximately 400 feet, and since in this well the interval is 291 feet only, it is safe to state that the sand in question is not the Second Cow Run. As will be discussed in another chapter, the term Second Cow Run is used by the driller and operator in a very loose way. It is applied to almost any sand lying from 100 to 500 feet below the First Cow Run. There is no method of distinguishing the sand except by its distance from the first one, and it is not widely recognized in southeastern Ohio.

The following log is from well No. 1 on the A. Mozier farm, one mile west from the village Chester Hill. The record was kept by W. H. Knight, the measurements having been made with a steel line:

	Thickness of stratum. Feet.	Total thickness. Feet.
Surface material	3	3
Limestone	31	34
"Big red" (shales).....	125	159
Sandy blue shales.....	22	181
<i>Ames limestone</i>	2	183
Blue shales	4	187
Black shales	8	195
Blue shales	10	205
Red shales	16	221
Dark shales	4½	225½
Limestone	2½	228
Blue shales	21½	249½
<i>First Cow Run sand</i>	12	261½
Gray shales	20	281½
<i>Cambridge limestone.</i>		

The following is a log of a well on the Lucinda Johnson farm, situated about 3 miles southwest of Brown's Mills:

	Thickness of formation. Feet.	Total thickness. Feet.
Gravel	4	4
Red rock (shales).....	10	14
Light shales	13	27
Sandstone	10	37
Limestone and shales.....	103	140
Light shales	10	150
Limestone	15	165
Red rock (shales).....	5	170
Light shales	5	175
<i>Mercer sand</i>	35	210
Limestone	5	215
Light shales	15	230
Red rock (shales).....	5	235
Light shales	10	245
"Big red" (shales).....	70	315
Light shales	15	330
Red rock (shales).....	10	340
Sandstone	4	344
Light shales	20	364
Black shales	12	376
Light shales	8	384
Red rock (shales).....	25	409
Light shales	8	417
Shales	10	427
Gray sandstone	5	432
Dark shales	15	447
Light shales	13	460
<i>Cambridge limestone</i>	4	464
Shales	9	473

It will be observed that in this section the Ames limestone is not reported. In fact, it is never recognized with certainty beyond Brown's Mills. The section shows the Cow Run sand also absent, its place being occupied by shales.

One more record only will be given. This is a well on the Mary J. Morris farm, near Brown's Mills. The data were furnished by A. J. Lockard:

	Thickness of formation. Feet.	Total thickness. Feet.
White shales	6	6
Red rock (shales)	24	30
White shales	10	40
Sand rock	4	44
Black shales	3	47
White shales	4	51
Limestone	12	63
White shales	2	65
Limestone	5	70
Shales and limestone	12	82
White shales	18	100
Limestone	3	103
White shales	6	109
Black shales	4	113
White shales	4	117
Gray sand	8	125
White shales	8	133
Limestone	4	137
White shales	12	149
Red rock (shales)	12	161
White shales	16	177
Black shales	20	197
Limestone	10	207
White shales	5	212
Black shales	20	232
White shales	12	244
Red rock (shales)	12	256
White shales	4	260
Black shales	4	264
Limestone	4	268
Red rock (shales)	4	272
Black shales	4	276
"Big red" shales	30	306
White shales	4	310
<i>Ames Limestone</i>	1	311
White shales	48	359
Sand	4	363
White shales	4	367
Black shales	20	387
Sand	10	397
Black shales	4	401
<i>First Cow Run sand</i>	29	430
White shales	17	447

The depth of the wells, of course, varies with the surface altitude; but few, if any, exceed 700 feet. One on the Hoon farm, at the end of the bridge at Brown's Mills, struck the oil sand at 393 feet.

The Oil Sand.—This, as has already been stated, is the First Cow Run. Its position below the Ames limestone varies considerably. An examination of 11 well records taken at random on the Dale farm showed a maximum and minimum distance of 92 and 71 feet, with an average of 82 feet; and the latter figure may be taken as an average for all the territory where the sand in question is found. It is rare that the interval exceeds 100 feet, or is less than 65 feet.

The sand varies much in texture. Sometimes it is so coarse as to make a conglomerate. Pebbles having a diameter of three-fourths of an inch are occasionally found, while those one-fourth of an inch are common. From these extremes the rock grows finer until it becomes so compact that it cannot contain oil or gas in commercial quantities. Sometimes the higher portion of the sand is quite fine or compact, and then is known as the "cap rock" among the drillers; while at other places the upper part is quite porous and contains important quantities of oil or gas. The sand is composed almost wholly of light-colored quartz, but other minerals, such as pyrite and mica are not uncommon. It is nearly colorless when first brought to the surface, but frequently changes to a yellow-brown when exposed to the atmosphere.

The pay streak, like the sand as a whole, varies much. It is usually the coarser part, and has a darker color. The drillers frequently describe it as having the shade of brown sugar. In thickness it commonly varies from 8 to 15 feet, but smaller and greater measurements are not rare. It is usually quite soft, so that the drill passes through it very quickly. Generally the pay lies a few feet below the top of the sand, but sometimes it is found at the summit. Occasionally also it lies at the bottom. Rarely the driller reports the pay rock divided by a few feet of shale, and then he announces the presence of two pays. An illustration of this is found on the Mozier farm, near Chester Hill, where the upper pay, having a thickness of ten feet, is separated from the lower one, having the same thickness, by ten feet of shale. Four wells similar to this have been found on the Dale farm.

In total thickness the sand varies greatly. Thus on the Dale farm 14 well records, taken at random, disclosed thicknesses ranging from 4 to 30 feet, with an average of 15. The rapidity of change is well shown on this farm by two wells 125 feet apart. One has 7 feet of the sand and the other 30 feet. The greatest thickness yet reported is in well No. 17, on the Mozier farm, where 47 feet of sand were found. It is not uncommon to find thicknesses of a foot or less, but such commonly occur along the margin of the field, and are rarely productive.

If there is one character of this sand which is more conspicuous than another, it is the discontinuous nature. This is often so prominent that it might almost be said to form a series of lenticular basins. A driller of wide experience in this field has estimated that in 90 per cent, of the dry holes near Chester Hill no sand was found, and it is a common statement among the drillers and operators that the failure to secure oil is due to the absence of sand. This is not always the case, however. When the sand disappears its place is taken by shales. These are sometimes siliceous, closely resembling the sand rock; but at other places they have no resemblance to the rock in question.

The texture of the sand is well shown by the different treatment with reference to torpedoing the wells. Those along the western end of the field are shot as soon as the drilling has been done, while farther east many of the wells have not been shot until a year or two after completion. The more open or porous the sand the less need of nitro-glycerine.

Oil has been found in a few wells near Chester Hill in shallower sands. One of these is the Wolf creek or Milner sand, which lies a few feet above the Ames limestone. Oil has been secured also in a stray lying about the same distance below the Ames. These, however, are of very little importance commercially. Their relations are shown below:

	Feet.
Wolf Creek sand.....	20
Shales	20
Ames limestone	2
Shales	25
"Stray" sand	18
Shales	40
Cow Run sand.....	15

One other sand should be mentioned. This is on the Mercer farm, about one mile due north of the junction of Coal run and Wolf creek. It was here that a well was drilled about 35 years ago, as has already been mentioned. The wells, however, are shallow, the oil sand being found at a depth of from 140-150 feet, while the First Cow Run probably lies 350 feet below the surface. This sand, which lies above the "Big red," is the highest stratigraphically of the producers in the northwestern part of Washington county. It is unimportant in a commercial sense, and does not give promise of becoming even a moderate producer. The sand occupies a similar position to that of the Mitchell, near Marietta.

In 1902 two deep wells were drilled east of Chester Hill and a reservoir of gas was the reward. The rock pressure was 400 pounds, and the open flow of one, measured by the Standard Oil Company, was reported to be 3,500,000 cubic feet per day. The second well had not been measured, but was reported similar to the first one. The gas has been piped to Chester Hill, where it is sold for 18 cents per thousand, with 10 per cent. off for cash.

Outside of the territory now described many wells have been drilled in search for oil. The valleys of the principal streams, especially that of Federal creek, have been the site of the most active operations. In sections 2, 7, 8, 13 and 14 of Ames township, Athens county, many wells have been sunk to the First Cow Run sand in recent years, but little more than a show of oil has been found. In the northeast corner of section 5, on the Linscott farm, several small producers have been secured, but 3 miles farther west, along the line of section 17, four wells have been drilled to the Cow Run sand, but nothing was found to compensate the operator for his outlay. In the northwest corner of Berne township, Athens county, several dry holes have been drilled. Two of these were on the O. & A. Gifford farm, in the northern half of section 30, and reached the Berea grit, which is reported to have been struck at a depth of 1,300 feet. These wells yielded much salt-water, but little oil, and are now abandoned. The wells in the adjacent sections of 29 and 30 went to the Cow Run sand and were all failures. Several Berea wells have been drilled near the Joy field, in Morgan county. In 1896 such a well was drilled on the L. L. Joy farm, in the southeast quarter of section 31, Homer township. The Berea was found at a depth of approximately 1,300 feet, but when this had been penetrated to a depth of 28 feet salt-water began to appear. Some show of oil and gas was found; but when the well was shot, the flow of brine increased, and after pumping for a time it was abandoned. Later a Berea well was sunk on the Hopkins place, in Marion township, just beyond the northeast corner of section 26. The sand there is reported divided as follows:

	Feet.
Berea (Upper stratum).....	24
Black shale	6
Berea (Lower stratum).....	15

Nearly 20 years ago a Berea well was drilled on the Boileau farm, near Joy. It is said to have reached a depth of 1,218 feet, but found nothing more valuable than a show of oil. About the same time a well was drilled on the Eli Swayne farm, in the northeast quarter of section 3, Homer township, and found the Berea somewhere between 1,300 and 1,400 feet. Neither oil nor gas was found in paying quantities, and so the well was abandoned. Many holes, aside from those here recorded, have been drilled both north and south of the productive strip, but the results achieved have been entirely of the negative kind. Doubtless many additional wells will yet be drilled in Homer and Marion townships, and considering the patchy nature of the sand it seems safe to predict that other small but valuable pools will yet be found.

THE BUCK RUN OIL FIELD.

Location and Area.—This field is located in the northeast corner of Union township, Morgan county, and in July, 1900, was confined to sec-

tions 1, 2, 3, 11 and 12. Work done since that time has not materially changed the field.

Discovery.—The people living along the valleys of Buck run and Wolf creek had, from the time of the settlement of the territory, noticed oil escaping at numerous points in the valleys of those streams, and they concluded from this that there might be reservoirs of oil in the rocks below. In the fall of 1860 a well was drilled on the east bank of Wolf creek, a few hundred feet above the point at which Buck run units with it, on the Ritchey farm, now owned by John Grey.

The well was a success, though only 37 feet deep. The oil sand lay immediately below the Amés or Crinoidal limestone. This lime rock has a thickness ordinarily less than 2 feet, is very hard, and so is easily recognized by the driller. It is filled with fossils, especially crinoidal stems, and is widely known among the oil men of southeastern Ohio as the "fossil rock." In fact, it is one of the geological landmarks of the driller, since one of the richest oil sands in that part of the state lies about 90 feet below it. The oil from this well being thick and heavy, was used for lubricating purposes, and was hauled in wagons to McConnelsville, where it found a ready market. At first the well was pumped by hand, but later by horse-power. The well was long-lived. It was not until about 1875, when the production had diminished to one barrel per week, that the well was finally abandoned.

Development.—The second well in this field was drilled on the Lewis Balding, now the Stanton farm. This well, however, was deeper, being the first one to strike the First Cow Run sand, which was found at a depth of about 120 feet. According to the best information obtainable at this late period, the well produced at first about 20 barrels per day, and it is of interest to report that it is still (1900) a producer. About 6 years ago the well was drilled deeper and cased to a depth of 40 feet to exclude the surface water. This well was pumped by horse-power from the first.

The Greathouse is another of the wells drilled in 1861. It was named after the driller and is located on the D. D. Scott farm, in the northeast quarter of section 11. When the sand was struck oil began flowing, and the necessary tanks not having been provided, dams were constructed across the creek, and in this manner the oil was saved until tanks could be provided. It is said that from 8 to 10 teams were kept busy hauling the product of this well to McConnelsville, 5 miles distant. About 1890 an attempt was made to clean the well, but in doing this a string of tools was lost in it, and the well abandoned. A new one was begun at once about 6 feet from the old well, and it has proved itself a worthy successor of Greathouse No. 1. In July, 1900, it was producing $2\frac{1}{2}$ barrels per day.

Another of the pioneer wells, still producing, was drilled in 1865 on the James Scott farm, in the central part of section 2. This farm is prominent in the oil production of the field, and so a line or two concerning the

history of the tract in question will not be out of order. About 1860 Mr. Scott leased for oil purposes a part of his farm to John Henry, of the adjacent village, Morganville. The leaser drilled 3 wells, 2 of which were total failures, while the third produced about $2\frac{1}{2}$ barrels only per week. After this well had been producing approximately 2 years, Mr. Scott purchased it and in 1865 had it shot, with the hope of increasing the production, but the shot ruined the well, and it was abandoned. In 1865 Mr. Scott again leased the tract under consideration, amounting to 15 acres, to the Chautauqua Petroleum Oil Company, of Chautauqua, New York, for which he was to receive one third of all the oil produced. Drilling was delayed until the company brought the necessary tools from New York, but 4 wells were completed that year, only one of which was a producer. This well, "The Chautauqua," yielded from 40 to 50 barrels per day for months, and it is claimed that if the pump had been worked to its full capacity the well would have produced 100 barrels per day. By 1869 the well had decreased to 6 or 7 barrels per day, and its owners, regarding it no longer sufficiently profitable, sold it to Mr. Scott, owner of the land, and to his cousin Andrew Scott. The price paid for the well and all machinery was \$1,100. The new owners of the well pumped it regularly until the refinery, "The McConnellsville Carbon Oil Company," went into bankruptcy in about 1873. Since that time it has been pumped irregularly and at present is a very small producer. The well is 118 feet deep. Water was found in the "fossil rock," which there lies about 30 feet below the surface, but was shut from the oil rock by the "seed-bag," which played so important a part in early oil development. The production of this well and market value of the oil from 1865 to 1873 was as follows:

	Barrels produced.	Value.
From August 15, 1865 to June 22, 1869.....	2,420	\$23,442
From June 23, 1869 to February 22, 1873....	1,610	6,692
Total	4,030	\$30,134

It is impossible to learn at this late date how many wells were drilled in this field during the time of greatest excitement, from 1861-65. From the best information obtainable, however, it appears that the valley of Buck run was dotted with wells as far up as and beyond Morganville, but that exploration did not extend into the adjacent valleys of Oliver run and Wolf creek.

By 1866 the greatest excitement in the valley was past, and when the refinery at McConnellsville was discontinued a few years later the best market for the oil was destroyed, though some is said to have been shipped by boat later to Marietta. After 1875 there was very little done in the field for many years, and the prospects were that it would never again attract the attention of oil producers. However, the Corning pipe-

line, which was laid in 1893, and passed near Buck run, encouraged the producer, since it removed the expense of hauling the oil to market. By 1897 considerable work was being done, and in 1899 the existing "boom" began. At present (July, 1900) 17 drills are at work, chiefly along Oliver run, a small tributary of Buck run, and along Wolf creek, about one-half mile from Oliver run. Since the wells are shallow, those in the valleys usually not exceeding 125 feet, the drill makes rapid progress, and it should not be long until the limits of the field are determined. In the sixties operations were confined to valleys, the driller having the mistaken idea that the productive territory did not extend beneath the adjacent hills. Now, however, the high lands as well as the valleys are tested, and fair producers found.

The following are the principal firms operating in the field at date of writing:

Malta Oil Company.
 Oliver Run Oil Company.
 Jerry Buckley.
 Christy Brothers.
 Elmer Taylor.
 Buzzard & Gibson.
 Ghering & Mahaffey.
 Moore & Downing.

Geology of the Field.—The surface rocks are in the main those belonging to the Conemaugh formation or Lower Barren Measures, the hill-tops alone rising to the horizon of the Pittsburg coal. The latter is represented by little more than a black streak, but the white limestone which underlies the coal is a prominent feature of the country.

The following log of a well on Oliver run represents the general succession in the field:

	Thickness of stratum. Feet.	Total thickness. Feet.
Light colored sand rock.....	43	43
Red rock (shales).....	90	133
Blue core (1st limestone).....	3	136
Blue shales	10	146
Red rock (shales).....	20	166
Blue core (2nd limestone)	3	169
White and red shales.....	30	199
"Fossil rock"—Ames limestone.....	2	201
Dark gray shales.....	50	251
Pink shales	6	257
Soapstone	15	272
Sandy shales	25	297
Black shales	35	332
Cambridge limestone	5	337
Black shales	70	407
Coal (No. 7).....	6	413

In this well the Cow Run sand was absent, its place being occupied by the sandy shales lying from 40 to 65 feet above the Cambridge limestone. This would make the interval between the base of the Ames limestone and the top of the Cow Run sand 70 feet, and this is the distance that is usually given along Oliver run. However, a quarter of a mile distant, along Buck run, the interval is 90 feet, and this is about the normal distance between these two formations in southeastern Ohio. The apparent contraction of the section along Oliver run raises the question whether the oil sand there is not a "stray" and the place of the Cow Run sand occupied by the black shales, which directly overlie the Cambridge limestone.

Salt-water is found everywhere in the field, but usually not in sufficient quantities to cause serious trouble to the operator. Fresh water is commonly found in the limestones ("blue-cores") above the Ames and in the latter stratum, and salt-water in the Cow Run sand. In the early days water was shut from the well by the "seed-bag," which consisted usually of a leather bag filled with flax-seed, but occasionally oats, wheat or some other grain was used. The bag was tied around the tubing at such a point that when put in the well, it would stand just below the point at which the water entered. The grain becoming wet would swell, completely filling the hole, and thus prevent the water from reaching the oil sand.

The Oil Sand.—This is a clean, porous, quartz sand. The quartz is colorless and distinctly vitreous. Usually the grains are angular, but occasionally a well-rounded one is found. The rock, which is the First Cow Run sand, is much more open than the Berea. It has a thickness ordinarily less than 25 feet, the oil being found in the upper 10, and salt-water below. It is overlaid by a fine-grained shale, sometimes called soapstone by the driller.

Here, as elsewhere, the sand does not form a continuous layer, but is patchy. It may run out, and be replaced by a shale in a very small area, so there is more than the usual chance of failure in this formation. Not infrequently a belt in which the sand is wanting may run directly across a productive strip. If the Berea grit be taken as a representative of the persistent beds of the state, then the First Cow Run may be selected to represent the opposite type. Its treachery is unusual for even a sandstone.

The sand does not contain sufficient gas to make the wells flow. Search has been made in the deeper rocks with the hope of finding sufficient fuel to pump the wells, but this effort has been only partly successful. Four small gas wells have been found near the junction of Oliver and Buck runs in a seam of coal reported 7 feet in thickness, and lying 205 feet below the Ames limestone. This is the position of the Upper Freeport or No. 7 coal.

Oil Production.—The largest well that has ever been secured in the field did not produce more than 100 barrels per day. At present the

wells are all small, though one on the Spurrier farm, along Wolf creek, is reported to have started at from 50 to 60 barrels. The largest well along Oliver run had an initial production of 12 barrels, while the average for that locality is about 5 barrels. The total production for the Buck run field does not exceed 100 barrels per day. Since the wells are shallow they are quite profitable, though small.

The oil compares favorably with that found in the First Cow Run sand elsewhere. It has a low specific gravity, and a market value equal to the Pennsylvania oil. The field does not promise to become one of future importance, though it will doubtless be a small producer for many years.

Wells in Union Township.—In the vicinity of Ringold, Union Township, an effort has been made to locate a pool. About 1896 a well was drilled on the Withee farm, in section 16. It produced a little oil, and since 1899 six additional wells have been put down on the same tract, all but one of which yielded a small amount of oil. The wells have a depth ranging from 80 to 204 feet, depending on the surface altitude. The sand, which is the First Cow Run, varies from 10 to 37 feet in depth.

On the Williams farm, in the southern part of the same section, four wells have been drilled, with results even less encouraging than those mentioned in the last paragraph. On the old Parsons land, in section 15, four wells were drilled about two years ago. All were producers, but were so small that they scarcely warranted pumping. In fact, at the time when they were visited by the writer they had not been in operation for two months. Wells have been drilled at a number of places between Buck run and Ringgold without success, and it seems safe to say that no important pool lies in that vicinity.

THE McCONNELLSVILLE GAS FIELD.

Location and Area.—This is a narrow strip extending a little east of north or west of south. It lies partly within the corporation of McConnellsville, and crosses the river near the lower part of the town.

Development.—In the spring of 1889 a well was drilled on the east bank of the river about one-half mile northeast of the city. The Berea sand was found at a depth of 1,195 feet, but the gas liberated was so small that the well was abandoned. About the same time a well was drilled three-fourths of a mile north of the city. It supplied enough gas for one residence.

These wells were failures, but the people were not satisfied. Some believed that gas would be found if only the drill were forced deep enough, and accordingly it was decided to attempt to reach the Clinton or Lancaster gas rock. However, no company was found that was willing to back so expensive and hazardous an enterprise, but the city, through its council, provided \$5,000 to explore further the territory. The well was located on the McConnellsville fair grounds, and work was begun Septem-

ber 3, 1894. The Berea was reached at a depth of 1,279 feet on October 24. It gave nothing more encouraging than a show of oil and gas, and many of the most intelligent citizens urged that the well be abandoned, and that the funds, of which a large part still remained, be used for drilling other wells near the city. The State Geologist was appealed to, and strongly advised that the well be abandoned, stating that even should the Clinton be reached and gas found, the expense of drilling such deep wells would be so great that the gas would be too costly to be used as a fuel. However, those in charge insisted on drilling deeper, and on November 8th work was resumed. Progress was very slow, and on March 14th, 1895, when at a depth of 3,186 feet, the tools became fast and the well was abandoned.

The following log of this well was kept by Mr. H. J. Travis, who kindly furnished it to the Survey. The stratigraphical names of the formation have been supplied by the writer. The well head is 725 feet above sea level:

Geological names of formations.	Driller's log.	Thickness. Feet.	Total depth. Feet.
Conemaugh Formation, or Lower Barren Coal Measures; Allegheny Formation or Lower Productive, and Conglomerate Coal Measures.	Surface material	15	15
	Fire clay	15	30
	Red rock (shales)	25	55
	Blue shales	30	85
	Limestone	15	100
	White shales	14	114
	Red shales	18	132
	Flint rock	5	137
	Blue shales	25	162
	Gravel rock	11	173
	Red shales	30	203
	White sandstone	14	217
	Yellow clay	15	232
	White sandstone	44	276
	Coal	2	278
	Shales	12	290
	Sandstone	6	296
	Shales	23	319
	Sandstone	39	358
	Shales	65	423
	Sandstone	20	443
	Gray shales	17	460
	Lime and gravel rock	35	495
	Shale and limestone	25	520
	Black shales	15	535
	Sand and shales	3	538
	Blue and brown shales	87	625
	<i>Marville or Mountain limestone</i>	44	669
	<i>Keener sand</i>	40	709
	Blue shale and sandstone	86	795
	<i>Big Injun sand</i>	45	840

Geological names of formations.	Driller's log.	Thickness. Feet.	Total depth. Feet.
Cuyahoga Shale.	White shales	71	911
	Brown shales	119	1,030
	Blue shales	25	1,055
	Black shales	194	1,249
	<i>Berea shale, Coffee colored</i>	30	1,279
Berea sand.	Berea sand	17	1,296
	Blue shale	34	1,330
	Stray sand (gas).....	15	1,345
	<i>Bedford sandstone and shales</i>	25	1,370
The Ohio Shales.	Black shales	70	1,440
	Sandstones and shales.....	66	1,506
	Black shales and sandstone.....	69	1,575
	Shales	60	1,635
	Bastard limestone	50	1,685
	Shales	270	1,955
	Shales and bands of limestone.....	9	1,964
	Shales and bands of sandstone.....	8	1,972
	Sandstone and limestone.....	58	2,030
	Shales	145	2,175
	Shales and limestones.....	71	2,246
	Shales	79	2,325
	Brown shales	55	2,380
	Coffee colored shales.....	82	2,465
	Black shales	18	2,483
	Coffee colored shales.....	97	2,580
	Limestone and shales.....	21	2,601
	Black shales	134	2,735
	Limestone and shales.....	159	2,894
	Flinty limestone and shales.....	38	2,932
	Brown shales	150	3,082
	<i>Corniferous limestone, hard</i>	2	3,084
	Flinty limestone	41	3,125
	Sandstone	8	3,133
	Limestone and sandstone.....	53	3,186

The presence of gas in the lower part of the Berea sand in this well encouraged further investigation, and in 1896 a well was drilled on the land of C. B. Bozman, about one-half mile east from the corporation line. The Berea there yielded a more liberal quantity of gas, and promised a moderate supply. In rapid succession wells were drilled in all directions from this one, until sufficient gas was secured to meet the demands of the town.

The Dresser Gas Company, which supplies McConnellsville and the greater part of Malta with gas had 18 producing Berea wells in July, 1900. Two of these are about one-half mile below McConnellsville, on the west side of the river, and the remaining 16 on the east side of the river. Two of the latter group are within the corporation limits. Besides these 18 wells the company has two shallow ones about three miles west of the

city, one on the farm of A. W. Powers and the other on the land of Mary Riley. The well on the first-mentioned farm is said to have been drilled nearly 40 years ago, but has been in use about 9 years only. The second well is reported to have been drilled 10 or 11 years ago. Both are now very small producers. The Dresser Company drilled its first deep well in 1896, and has sunk one or more wells of this type each year since.

In 1897 the Home Gas Company of Malta was established. In the summer of 1900 it had three producing wells, all of which were small, supplying approximately 50 families. The Dresser Company reports that it supplies 700 families. The charges are 10 cents per 1,000 cubic feet, but if the bills are not paid when due 10 per cent. is added. It is claimed that this rate does not pay the expense of operating the plant. Before the Home Company was established the rates were just double those stated.

The Gas Sand.—With the exception of the two wells noted, the sand is the Berea. This divides here, the two parts being separated by a bed of shales which is 30 feet thick on the west side of the river and 20 feet thick on the east side. The gas is derived entirely from the sand below the shales and is known locally as the "stray," that above the shales being considered as the Berea. The lower bed or "stray" ranges in thickness from 7 to 29 feet, and the upper bed is probably confined to about the same limits. Wells drilled near the river on the north side of the county show this parting, but on the east side of the county it disappears, and the same is true near the river 3 miles south of McConnellsville. The casing reaches through the Big Injun sand, a depth in the valley of approximately 800 feet. Below this no water is found until the Berea is struck. The quantity found there is not large, and is restricted to the upper stratum. The wells are shot with from 40 to 80 quarts of nitro-glycerine.

Rock Pressure of Gas.—The Dresser Company reports the closed or rock pressure of the gas as having ranged from 380 to 545 pounds per square inch in 1899. Before that date the pressure was never measured. The open pressure, and hence the production of the wells, has never been determined. That this is small is shown by the fact that 23 wells are required to supply the towns of McConnellsville and Malta, the combined population of which is perhaps 3,000.

The operators have the usual trouble from salt-water. During the winter months the wells have to be "blown" every other day, but during the summer this does not have to be done at all.

Within the past few years a number of wells have been drilled in the northern part of the county. In September, 1899, one on the land of William Porter, at Shawnee Junction, reached the Berea at approximately 1,125 feet, but neither oil nor gas was found. In 1897 a well was drilled on the Hite farm, on Island run, about one mile from Eagleport. This well made little more than a show of oil. It was pumped irregularly for a month, producing perhaps 20 barrels in all, and then was abandoned. In

1899 a well was drilled on the McCauley farm, about 2 miles northwest of the well just mentioned. The Berea was found at a depth of 1,175 feet, and was divided as follows:

	Feet.
Sandstone	12
Light colored shales.....	35
Sandstone and shale ("stray").....	10

Below this a brown shale (the Bedford) was found. The well produced neither oil nor gas. A well drilled in June, 1900, on Cedar run struck the Berea at 1,073 feet, but neither oil nor gas was found. Other wells have recently been drilled in this part of the county, but all have been failures. It is reported that formerly 5 wells were drilled in this territory and all produced much oil. This report is in part responsible for the wells that have recently been drilled.

OIL AND GAS IN WASHINGTON COUNTY.

This county is one of the oldest producers of oil and gas in the United States. Forty years before the drilling of the Drake well near Titusville, Pennsylvania, in 1859, the county was yielding crude oil. The discovery resulted from boring for salt-water. One of the earliest of these wells was located on the Little Muskingum river, and was thus described by Dr. S. P. Hildreth, one of the pioneer geologists of the state, in a letter written in 1819 to Mr. Caleb Atwater, of Circleville, and by him published in the *American Journal of Science* in 1826:

"They have sunk two wells which are now more than 400 feet in depth. One of them affords a very strong and pure water, but not in great quantity. The other discharges such vast quantities of petroleum, or as it is vulgarly called 'Seneka oil,' and besides is subject to such tremendous explosions of gas for several days that they make but little or no salt. Nevertheless, the petroleum affords considerable profit, and is beginning to be in demand for lamps, in workshops and manufactories. It affords a clean, brisk light when burnt this way, and will be a valuable article for lighting the street lamps in the future cities of Ohio."¹

That these early drillers for salt had some experience with natural gas is shown by the following extract from the same letter:

"There is a continual discharge of carbonated hydrogen gas from the well; and also from the bed of the creek on which the well is situated, at various places for the distance of half a mile. This gas is highly inflammable, and where there is a free discharge of it, will take fire on the surface of the water, on the application of a lighted stick, or the flash of a gun, and continue burning for days, unless put out by a heavy shower or a high wind. It was this discharge of gas that induced the present

¹*Amer. Jour. Sci. and Arts*, Vol. X, p. 5, S. P. Hildreth.

proprietors to search for salt-water. It being invariably found to accompany, all the salt-water, of any consequence, that has been discharged in this western country.

"It is this discharge of gas that brings the salt-water from such vast depths in the bowels of the earth, to the surface. And where water has been discovered, and the supply of gas has failed, the water has immediately sunk in the well, and could not, by any means used, be brought again to the top of the well."

Just as Washington county was one of the first producers of oil, likewise Marietta, the county seat, was one of the first distributors. The principal supply was derived, however, from West Virginia and not from Ohio. One of the pioneer firms was Bosworth, Wells & Co., who began purchasing the crude material from Bushford W. Creel, of Hughes River, West Virginia, in 1847 and continued until 1860. The firm shipped the oil to Pittsburg, Philadelphia, Baltimore, New York, St. Louis, Peoria, Chicago and Cincinnati. From 1848 to 1857 the firm received 33 cents per gallon for the oil, and from 1857 to 1860 40 cents per gallon.¹ The opening of the Pennsylvania field in 1859 destroyed the business of Bosworth, Wells & Co., in so far as it depended on the shipment of crude oil from the Hughes river territory.

While the crude material may have been used by the drillers and farmers adjacent to the wells for illuminating, it is probable that the chief demand for the oil in distant cities was for medicinal and lubricating purposes. It is said that large quantities were used in the manufacture of the Mexican Mustang and other liniments. The crude oil was at that day regarded as an excellent remedy for rheumatism, and indeed many so regard it at the present time.

The discovery of oil in large quantities in Pennsylvania in 1859 stimulated investigation wherever surface indications, consisting of oil floating on streams, or filling sands in valleys, or the escape of gas through crevices in rocks, were found. Among the tracts of this kind in Washington county was the valley of Duck Creek at Macksburg, in the extreme northern corner and the insignificant valley of Cow Run, in Lawrence township. Mr. F. W. Minshall² has already published an interesting account of the early developments in this field, but since this report is now out of print, the salient points are restated here with such additional data as the writer has been able to secure.

Discovery of Oil at Macksburg.—This was one of the first fields developed after the discovery in Pennsylvania. In the fall of 1860 Messrs. James Dutton, Alden T. Warren and John Smithson decided to drill a well on the land of William Rayley, situated in the valley of Duck creek, about one-half mile below Macksburg. The method of drilling was of the

¹*W. Va. Geol. Sur.*, Vol. I, p. 142, I. C. White.

²*Geol. Sur. of Ohio*, Vol. VI, Chap. 6.

most primitive sort, the tools being raised by a hand lever. Necessarily the labor was arduous and progress slow. Fortunately it was not necessary to drill deep; at a depth of 59 feet oil was found in moderate quantity. It had a gravity of 28 deg. B., and because of this did not find a ready market, since it was too heavy to be used for illuminating purposes. However, its value as a lubricant was soon discovered, and thereafter the product was easily disposed of, commanding a price as high as \$28 per barrel. The oil was hauled in wagons to Lowell, on the Muskingum, ten miles distant, and from there shipped by boat. The success of the Dutton well at once attracted the attention of operators elsewhere, and soon the adjacent territory was being tested. A little later it was decided to drill deeper, and at 140 feet below the valley of Duck Creek a second sand was found which produced quite largely. This is the equivalent of the sand found on Cow Run—to be discussed later—and now widely known in southeastern Ohio as the First Cow Run sand. It is known at Macksburg, at the present day, as the 140-foot sand. A year or two later a well was drilled on the Smithson farm, in the valley below Macksburg. At a depth of approximately 300 feet a small amount of oil was found, and this rock has been known as the Macksburg 300-foot sand. In 1865 a well was drilled on the Atkinson farm, just below Macksburg. At a depth of 500 feet a flow of oil, reported at 50 barrels per day, was found, and this stratum has since been known as the 500-foot sand. The same year a well was drilled to a depth of 800 feet on the Dutton farm, below Macksburg. It produced gas and some oil, and the oil rock has since been known as the Macksburg 800-foot sand.

The greatest excitement in the field was perhaps in 1864, when land was bought and sold at fabulous prices. Thus the Jacob Dearth farm, consisting of 200 acres, and adjoining the Dutton tract, just below Macksburg, was sold for \$300,000. At that time there was one well on the tract which produced about ten barrels per day. The company never secured another producer. About the same time the James Dutton farm sold for \$100,000. A small part only of the farm which exchanged hands was regarded as productive, since not more than a fraction of the territory lay in the valley, and this part alone was regarded as productive. Not until 1881 (Minshall) was the hill land adjacent to the valley tested.

The period of great excitement just alluded to was of short duration. The deeper sands did not meet expectations and the expense of hauling the oil to market was heavy. Besides the price of oil had decreased, and as a result of these conditions the principal operators withdrew from the field, and the valley resumed much of its old-time quietude.

Discovery of Oil at Cow Run.—The following interesting paragraph is taken from Mr. Minshall's report, to which reference already has been made:¹

¹*Geol. Sur. of Ohio*, Vol. VI, p. 414.

"In the winter of 1860, Mr. John Newton, of Marietta, Ohio, was one day sitting in his office at the Harmar Bucket Factory, when his attention was called to a newspaper article on the subject of drilling wells for petroleum in Canada. In this article natural gas springs were mentioned as indications of underlying deposits of oil. Mr. Newton read the article aloud. Among the listeners was Mr. Uriah S. Dye, one of the workmen at the factory. After the reading was finished, Mr. Dye informed Mr. Newton that he had one of those gas springs on his farm at Cow Run, in Lawrence township; that the spring had been a source of curiosity for many years to the owners of the land, and that a crude attempt had been made to use the gas as fuel by a Mr. Guyton, who had a cooper shop near by. Mr. Newton was finally persuaded to go out with Mr. Dye and look at the spring. As a result of the investigation, a company was formed, composed of Jno. Newton, Douglas E. Newton, William Naylor, Moffatt Dye, and Geo. S. Bosworth. On the 2nd of February, 1861, leases were taken by the company from Uriah S. Dye, covering the W. $\frac{1}{2}$ of N. W. qr. of section 19, and W. $\frac{1}{2}$ of S. E. qr. of N. W. qr. of same section, in all 100 acres; also from Samuel Dye the N. E. qr. of N. W. qr. of section 19, 40 acres. Drilling was commenced at once, the first well being located close to the gas-spring. The machinery then in vogue was the 'spring-pole' and 'treadle;' the motive power, human muscle. In that day it was essential that the driller be both sound in wind and limb. The first Newton well was, however, soon kicked down to what was then supposed to be a sufficient depth, and 'came in dry,' barely showing enough oil to grease the tools. Instead of being discouraged, Mr. Newton seized a shovel and said, 'Come, boys, I'll show you where to get an oil well.' He went over to the Samuel Dye 40 acres, chose a spot on the main run where the gas could be seen bubbling up through a pool, and by night had a pit dug down to the gravel. In the morning the water in this pit was covered with oil. The 'kicking process' was speedily resumed, and at a depth of 137 feet their labors were rewarded by striking a 'gusher.' The well did not flow; it was pumped with a spring-pole, and each day's product put into barrels—the pumping and filling of 50 barrels was about an average day's work for two men. The oil was taken by wagon nine miles to Marietta, and sold chiefly to Mr. William Finley, buyer for a refinery located at St. Louis, Mo."

Below is another account written by Judge L. W. Chamberlain, of Marietta and published in the Oil News, July 29, 1899:

"On February 2, 1861, John Newton, William Naylor, Moffatt Dye, George S. Bosworth and Douglas E. Newton, all of the Marietta Bucket Factory, procured a 10 year lease from Uriah S. Dye, on his farm at Cow Run, and on February 4th, same year, they took a lease of Samuel Dye (the second) on forty acres adjoining the above and proceeded on a wild cat venture to put down a well, the first in that locality.

"Oil had already been discovered at Macksburg, and what turned the attention of these men to Cow Run was a gas spring long known to the inhabitants in that locality, where gas had for years prior been utilized for heating and lighting purposes.

"The well was put down to a depth of about 160 feet, where oil was found, but the surface water was a great obstacle in the way of successful pumping. Finally a 'seed-bag' was placed on the tubing and crowded down to the proper depth to cut off the surface water, and after pumping off the water below, a fine production of oil was procured, and the Newton well was started on its successful road to fame and fortune. From this time on the development was quite rapid, and other wells were put down by the slow process of the 'spring-pole.' This was a tedious means of getting them, but two men would tramp down a few feet each day, if no bad luck interfered, and finally the rock would be reached and the reward obtained, unless the operators became discouraged and sold out for a mere pittance. One well actually changed hands three times during the drilling, and was many months getting down, the last and successful operators drilling but a few feet before striking a valuable production on an outlay of but a few dollars.

"The Newton leases were for one-fifth of the production as royalty, but afterwards the excitement ran so high that one-half was paid as royalty, the lessors to furnish barrels to haul the production. After a few years the Newton property fell into the hands of the Bergen Oil Company, a corporation from the east. This company, loaded down with many purchases in addition to this tract, finally became involved to such an extent that judgment was rendered against them in our court for about \$30,000, and the property was put into the hands of a receiver, the court appointing Sheriff Hicks receiver, who proceeded to pump the old well and sell the oil until the judgment and costs were satisfied from the proceeds of this well, and the property turned back to the company. During the receivership the oil was sold at auction, and one lot sold at \$15.25 per barrel at the well. No wonder that judgments could be paid and fortunes made at such prices for oil. All the world seemed to drift toward the Mecca of Cow Run then, and fabulous prices were paid for interests and the territory was cut up into small holdings. Finally leases began to expire, and the territory was bunched up into large tracts, and to-day the two largest holders are the Bergen Oil Company and the Lehmer tracts, our fellow townsman, George S. Lehmer, operating more than twenty wells. At one time there was a community of thousands at the Run, and the hungry prospector had a hard time to find rations.

"Many men were making ventures by putting in their labor and relying on borrowing or hiring tools and much borrowing was done when the owner was not looking. Two poor fellows had been tramping the treadle all one cold winter trying to get to the sand, one with a family of half-

starved and worse clothed children, when one day they got the rock and a good showing of oil, which so excited them that the pater familias hallooed over to his wife that they could have meat for dinner that day, and I suppose a rare feast was the result. After a while Mr. C. C. Church laid a pipe-line to the river at the mouth of Bells run, Newport township, and instead of 50 cents per barrel for hauling, the pipe-line rate of 25 cents was welcomed, but prices also dropped and profits to the producer were not so great, even with cheap rates of transportation. The range of prices has been from \$16 to 50 cents per barrel. Oil men are great on names and every well has its name. The Newton well came to be called the Old Cow, and then came the Heifer, the Dead Dog, Dolly Varden, Grecian Bend, Beech Tree, Willow Wells, School House well, Comet, etc.

"I doubt if we shall ever see in this county again such a jam of human beings and capital on so small a space of territory."

The production from these early wells does not appear to have been large, for according to Mr. F. W. Minshall's estimate the total yield of the field from 1861-67 was only 50,000 barrels. However, there was great expectations, and the usual excitement. Territory that was regarded as productive sold at exorbitant rates. Here, as elsewhere, it was thought that the producing sand was limited to the valley, and not until 1869 were the adjacent hills tested. By 1865 the first boom was over, and little work was being done. Mr. Minshall's report of the field at that period is as follows:

"The Bergen Company, having suspended drilling, was pumping its ten barrels per day from the two Newton wells. The oil was bringing a good price, selling in the summer of 1865 for \$14 per barrel at the wells. The company finally decided to divide its Cow Run territory into two-acre lots and sub-let them at one-third royalty. The first lease was taken by Isaac Perkins in March, 1866; three lots of two acres each were let with the understanding that he was to drill to a depth of 600 feet unless a paying well should be sooner obtained. The first well was begun soon after the lease was taken, but was not completed until the following winter. The well head is forty-eight feet below the Pomeroy coal, and 666 feet above sea level. In the Cow Run field the shales of the Lower Barren Coal Measures gave the driller a great deal of trouble by caving in and filling up the drill hole. It was found necessary to case from one to three times with sheet iron casing to shut out these caves. The tools were lost several times in the Perkins well, but were fished out again, and in November, 1866, the top of the Second Cow Run sand was struck at a depth of 595 feet. When the bit had penetrated the sand about five feet the well began to flow. It was tubed with a two-inch pipe and a seed-bag, and turned into a 250 barrel tank, which it filled in two days. The well continued to flow 100 barrels per day for several months, and kept its owners busy building tanks to hold the product, the only means of transporting the

oil to market being by wagon nine miles to Marietta, over roads which were at that time of the year almost impassable."

It is important to note that the Perkins well was the first one in this field to reach the Second Cow Run sand. It caused renewed excitement, and probably led to the period of greatest activity in the territory, when the derricks were so close together that it was difficult to drive a wagon through the valley. According to Mr. Minshall the production of the field from January, 1867, to August, 1868, was about 150,000 barrels. At first the oil was hauled to Marietta, nine miles distant; but in times of high water in the Ohio there was slack water in the Little Muskingum as far as the mouth of Cow Run, and small steamers carried coal to the latter point and took back oil. At times, when the water in the Little Muskingum became too low for steamers, flat-boats were used to float the oil to the Ohio. In 1868 a two-inch pipe line was laid to the Ohio river, about three miles below Newport, and thereafter the transportation of the oil was a comparatively easy matter.

Having now reviewed the history of the discovery of oil in the Macksburg and Cow Run fields, the development and subsequent history of these pools will be given and then the numerous other pools of the county discussed. The description of the latter will begin in the western part of the county and proceed eastward, without regard to the time of discovery and development of the territory.

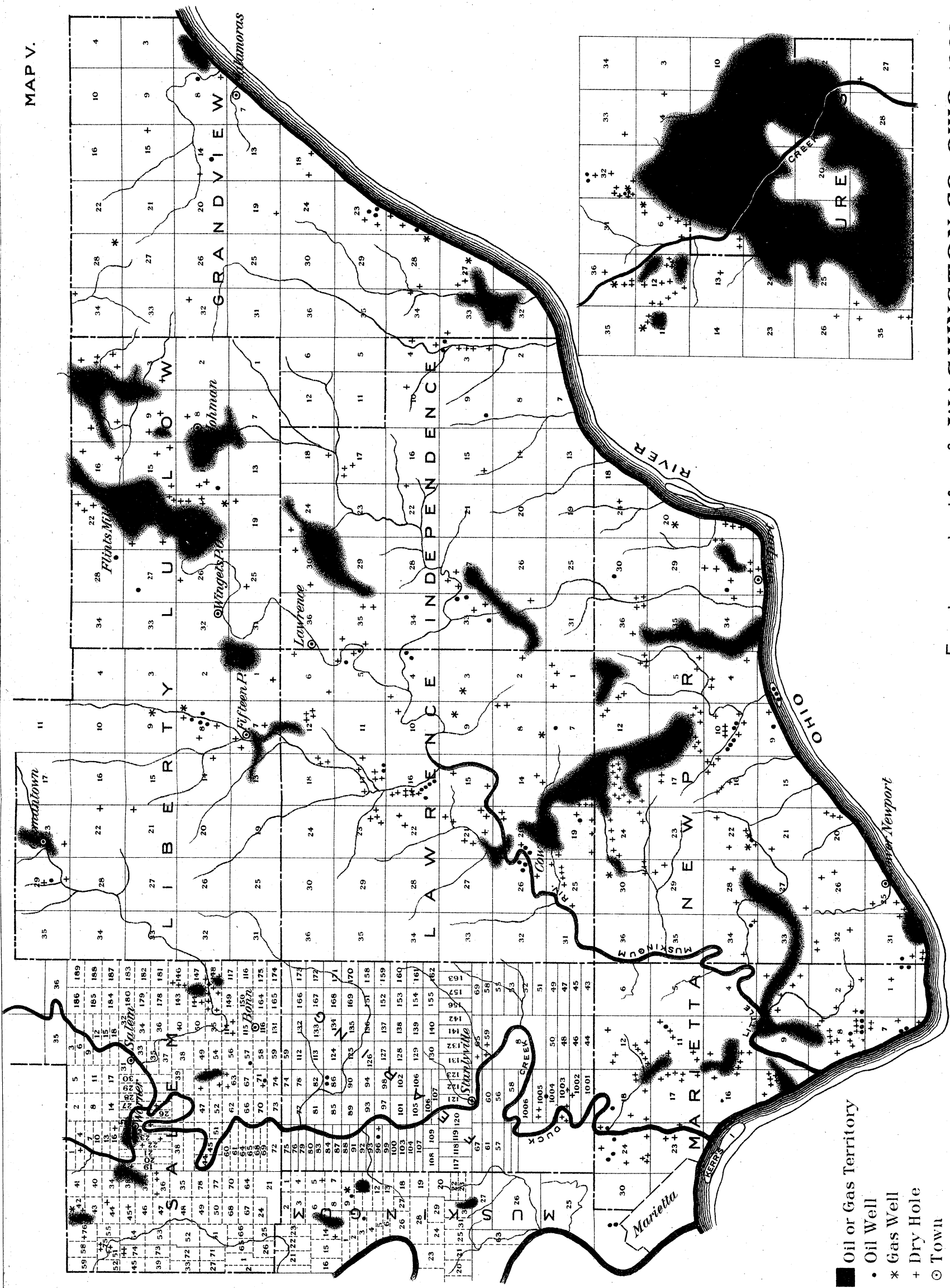
DEVELOPMENT OF THE MACKSBURG FIELD.

During several years following the first boom the valley was very quiet. A number of wells were pumped, but there was little drilling. This resulted from several causes. The productive territory was thought to be limited to the valley, and since this is narrow it was soon drilled over; the price of oil had decreased until it was a fraction only of what it had been before, and besides the expense of hauling the oil to Lowell, ten miles away, was too great considering the price of oil.

The period of revival began in 1874 when George Rice secured a 150 barrel well in the 140-foot sand. This encouraged drilling, and by the close of 1877 over 30 wells had been put down in the vicinity of Macksburg. The best of these, located on the Egler tract, started at 500 barrels, but the wells were nearly all small or total failures. None appear to have gone below the 500-foot sand. The next step in the development of the field was the discovery of the Berea, and because of the importance of this Mr. Minshall's account is reproduced:

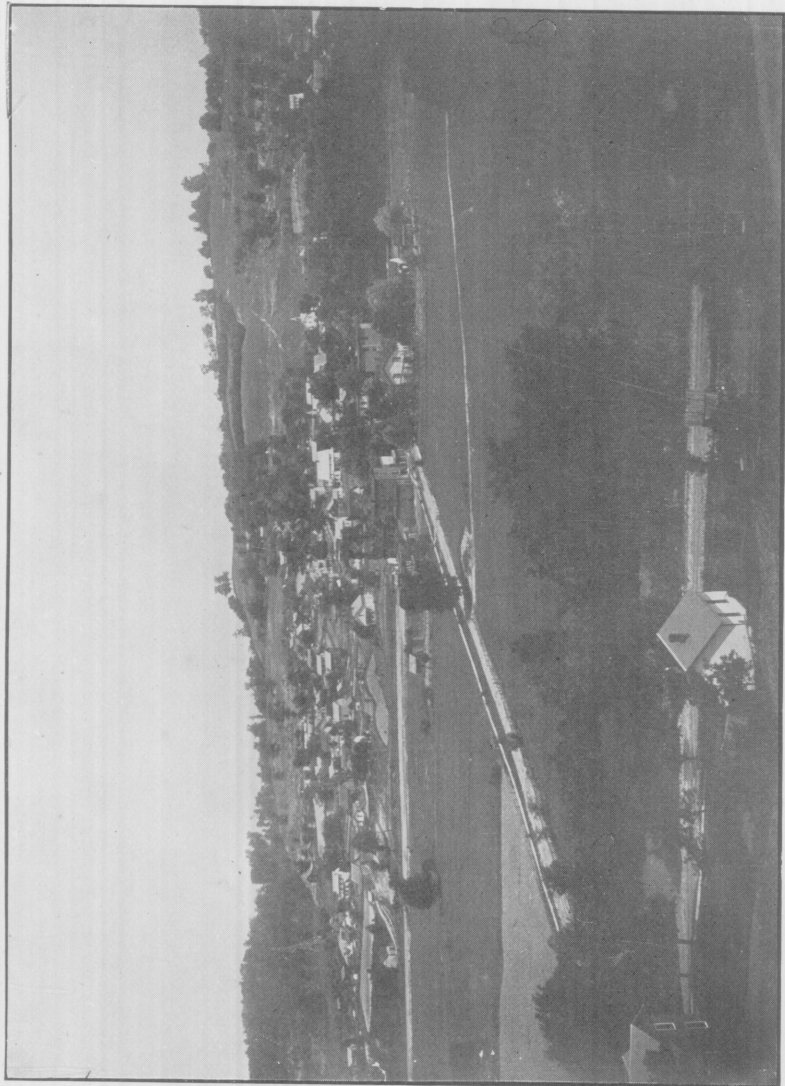
"In the summer of 1877 an attempt was made to extend the Macksburg field in a northerly direction by drilling a well for the 500-foot sand on Buffalo Run. Some years before a well had been drilled on the Slaymaker farm, on this run, which made a fair showing of oil that was supposed to come from the 500-foot sand. The well had been abandoned by

MAP V.



Eastern half of WASHINGTON CO., OHIO. 1902

PLATE IV



MACKSBERG AS IT IS TODAY

its owners, but the oil continued to rise through the water in the well and accumulate in the conductor, from which it was dipped and carried away in jars by the natives as a cheap lamp oil.

"The gentleman who first proposed the venture was a Mr. Williams, of Dexter City. Not having sufficient capital to carry out his plans, he made the following proposition to the writer: 'To any one who would furnish the use of the machinery, tools and casing to drill the well, he would give one-fourth of the oil obtained; machinery, tools and casing to be returned in good order, ordinary wear excepted, if no oil obtained.' Parties were found who accepted this proposition, and Mr. Williams commenced operations. The location chosen by him was on the bed of Buffalo run, Matthew Mitchell farm, which lies just below the Slaymaker tract. Mr. Williams was afterward joined by Captain Mosely, and the well was sunk by them to a depth of 800 feet without obtaining oil in paying quantity. These particulars are given at some length because this is the well by which existence of the 'Berea' sand in the Macksburg field was proven. After Messrs. Williams and Mosely had abandoned the well, the parties who owned the machinery and tools were persuaded by the writer to drill it down in search of the 'Berea,' which was then yielding oil in the White Oak district of West Virginia. Careful measurements of the intervals between the Ames or crinoidal limestone and the 'Berea' had been made in the West Virginia field, where it was found to be about 1,400 feet. The position of the Ames at Buffalo Run was known by him to be about 70 feet below the bed of the river on the Mitchell farm. It was, therefore, decided to drill the well to a depth of 1,500 feet, if the rock should not be found at a less depth. The interval at Macksburg proved it to be somewhat less than at White Oak, and the top of the sand was struck at 1,427 feet. The well was drilled wet and was standing full of salt-water; when the first bit was run in the sand it began to show gas, and the second bit developed enough gas to throw the brine over the top of the derrick and empty the well. In order to complete the well it was necessary to place an oil saver upon the casing-head to prevent the driller being pickled. Below the gas a thickness of 15 feet of very fine white sand, containing the rainbow colors of petroleum was found. The well was tubed with packer and two-inch pipe, but yielded nothing but dry gas. It was never torpedoed. The odor of the gas was exactly like that of petroleum, but this and the colors were the only evidence of the propinquity of this venture to the richest portion of the Macksburg field."

The first producing well near Macksburg in the Berea sand was secured in 1879 by George Rice. Besides sufficient gas to pump the shallow wells, it flowed 15 barrels of oil per day. The third Berea well was started in 1881 on the Lund farm. It produced much gas, but no oil. In 1882 three wells were drilled—one each on the William Dearth, A. Perkins and William Atkinson farms. All were small oil wells. In 1883 a well was

drilled on the Ohio Coal Company's lands which started at 100 barrels. This was the first of the large Berea producers, and at once led to extensive operations.

The Second Stage in the Development of the Field.—One of the results of the discovery of oil in the Berea was the testing of the territory outside of the valley. The demonstration that oil existed beneath the hills greatly extended the possibilities of the field. After the completion of the 100-barrel well referred to above, others were drilled in rapid succession, the tools moving in all directions until 1885, when the limits of the field had been determined. This extended almost as far north as Dexter City, as far south as Elba, two and one-half miles east of Macksburg, while the western boundary was practically limited by Duck creek.

The largest producers were secured on the George Dyer farm, one and one-quarter miles northeast of Macksburg in section 5 of Jefferson township, Noble county. Two wells on this place, drilled in 1885-6, are reported to have started each at 400 barrels, but the great body of Berea wells in the field started at from 15 to 60 barrels. All contained sufficient gas to flow the oil, thus diminishing the expense of operating them.

As has been previously stated, one of the early difficulties was the transportation of the oil, and as the production of the field increased the problem became more serious.

The completion of the Cleveland & Marietta railroad gave temporary relief, for in 1883 a pipe line was connected with it, the oil being transported in tank cars. A year later a line was laid to the Muskingum river, near Lowell, and the oil loaded on boats. In 1885 the National Transit laid a three-inch line to Parkersburg, West Virginia, and from that time the transportation of the oil has been a comparatively easy problem.

The Berea wells were drilled wet, the casing usually extending to about 65 feet below the 140-foot sand, but occasionally it went to the 300-foot. The object of the casing was merely to prevent caving, and not as at present to exclude water also. When drilled the salt-water was kept from the oil rock by placing a packer around the tubing a few feet above the sand. This could not subsequently be removed, since the salt-water above would at once enter the sand and cause a deposit of paraffine around the hole, thus shutting out the oil. Hence, when sand obstructed the holes in the bottom of the tubing, or the pores in the rock in any manner became closed, the production of the well ceased though the oil had not been exhausted. This was very unfortunate, since it has made necessary the re-drilling, at a great expense, of the entire Berea producing territory.

The production of the field increased rapidly as well after well was drilled. In August, 1884, it was 4,600 barrels; in December, 1884, 10,000 barrels; in March, 1885, 21,600 barrels; in July, 1885, 79,700 barrels. From that time there was a decrease, the output having been 66,175 in December, 1885, and 57,700 barrels in February, 1886.

As a rule these wells were long lived, and several are still producing. According to Mr. C. G. Dutton, of Elba, one is found on the Walter farm; another on the Coal lands, and a third on the A. Morris tract.

Development of the 500-Foot Sand.—Drilling for the Berea led to another result of great importance viz., the discovery over considerable areas of valuable deposits of oil in the 500-foot sand. According to Mr. Minshall the first producing well in this sand was drilled on the Atkinson farm, just below Macksburg, in 1865,¹ but others give earlier dates. Thus Mr. Orton Dunn, of Dexter City, states that a well drilled on the Keith farm in 1861 struck the sand in question at a depth of 448 feet, and that the well produced 100 barrels of oil the first day. Mr. Dunn also states that the well continued producing until 1899, when it was abandoned. Mr. Frank Ayers, of Macksburg, informed the writer that in 1863 a well was begun on the land of the Lowell Oil Company near Macksburg, and reached the 500-foot sand the following year. It is claimed that this well has produced continuously from that time, except during short intervals when it was closed for repairs. At present it yields about one and one-half barrels per day. Mr. Minshall's familiarity with the field, however, gives his statement much weight. All agree, however, that active work in the sand did not begin until 1865, and even then on a comparatively small scale. In 1866, 1878, 1888 and 1890, wells were drilled to the 500-foot sand on the Keith (now J. S. Dunn) farm. All made some oil, and it is difficult to understand why drilling on this tract did not become active until 1890. In the latter year there were 16 producing wells on this farm, consisting of 72 acres. The northern part of the Macksburg field, in so far as it relates to the 500-foot sand, is confined to sections 11 and 12 of Jackson township, and 5, 6, 8 and 32 of Jefferson township, Noble county. During the past ten years work in this sand has been active, and it appears from the dry holes that the limits of this part of the field have been pretty definitely determined. In one only of these sections, viz., 6 of Jefferson township, are wells found in both the 500-foot sand and the Berea.

South from Macksburg active work in the 500-foot sand began about 1885, and is still in operation (1902). The territory includes sections 24, 25 and 36 of Jackson township, Noble county, 7, 17, 18, 19, 29 and 30 of Aurelius township, Washington county, and a strip one-half mile wide and one and one-quarter miles in length along the line of junction of Adams and Salem townships, Washington county. Many of the wells in the southern part of the field have been abandoned. Thus, on the J. Gessel farm of 103 acres, one mile west from Macksburg, 14 wells have been drilled, 11 of which were producers, but 7 of these have now (1900) been abandoned. The combined production of the four is ten barrels per day.

¹*Geol. Sur. of Ohio*, Vol. VI, p. 450.

The best well on the farm started at 140 barrels per day. On the S. Gessel farm, lying immediately south of the one just mentioned, there were formerly nine producers, but all have been abandoned. The largest well in this part of the field was reported on the Isaac Reed farm, in section 36 of Jackson township, Noble county. Its initial production was 200 barrels daily, and it is said to have kept up this rate for a month. Early in the history of the field the wells yielded sufficient gas to supply the boilers for pumping, but in many places the flow has become so weak that coal is now used. The points just given concerning these three farms apply almost equally well to any others in this part of the territory.

The pool lying along the line adjoining Adams and Salem townships, Washington county, is at present separate from the territory northward, and is commonly known as the Lowell field. It was discovered late in the summer of 1898, and drilling has been active since that time. The principal farms are the Minsch, Dovenberger and Rausch. Of these the first named is the best, there being 22 oil and 1 gas wells on it in September, 1900. The production of oil on this farm was 150 barrels per day at that time. The gas well had an initial rock pressure of 400 pounds, but had not been used for purposes other than those on the lease. Seven wells had been drilled on the Rausch farm, which joins the Minsch on the south, at the time mentioned. Of these six were producers, the combined output of which did not exceed 40 barrels per day. The Dovenberger farm joins the Minsch on the north. Of the 11 wells drilled on that place 6 were producing, three were dry and 2 were abandoned. These wells then made approximately 180 barrels per week. In 1901 the pool was extended by the discovery of oil on the Fauss farm, lying to the south. A well drilled on the Wunderlick farm about July 1, 1901, started at 240 barrels per day, and a year later was still flowing 25 barrels. Fourteen wells, all producers, have been drilled on the Spies farm of less than 50 acres, the best one having an initial production of 125 barrels. The development of this territory makes practically a continuous strip from Macksburg to the Muskingum river near Lowell.

Development of the 140-Foot Sand.—Besides the Berea and Macksburg 500-foot sands which have now been discussed, there is still another important producer in the field, viz., the Macksburg 140-foot sand, which as has been previously stated appears to be equivalent to the First Cow Run. This territory lies south of Duck creek, in Aurelius township, Washington county, and includes sections 17, 21, 28 and 29. One of the best farms, owned by W. R. Wickens, in the last named section, contained in 1900, six wells in the 500-foot, and perhaps 20 in the 140-foot sand. The first and best of these shallow wells was drilled about 1885, and started at 180 barrels per day. This included, however, not only the production of the 140-foot sand, but also that

of a "stray" lying 40 feet higher. One of the wells on this place, having its surface two feet below the Meigs Creek coal, struck the 140-foot sand at 380 feet, making the interval between the two, 382 feet. Another well, about 200 yards from this, started two feet above the coal and found the 500-foot sand at a depth of 724 feet. Occasionally these wells flow when first drilled, but as a rule they have to be pumped from the start. Oil taken from a tank connected with the 140-foot wells had a gravity of 40 degrees B. The Shimmel farm, comprising 300 acres, is another important one. The best well, drilled in 1888, started at 180 barrels, but the greater number had an initial production ranging from 4 to 60 barrels daily. The number of holes drilled on this tract is large, and according to the proprietor not less than 30 have been failures. Other farms in this part of the field merely duplicate what has been said, and so will not be mentioned.

Other Sands.—Besides the three sands discussed there are others which furnish a little oil. Just west of Macksburg, on the east bank of Duck creek, are three wells in a shallow sand. These were drilled in the spring of 1898, and have depths of 68, 70 and 72 feet. They began producing from 1 to 3 barrels daily, but have decreased so that they are no longer pumped regularly (1901). The oil is said to have a gravity of 28 degrees B., and is sold in the vicinity at 20 cents per gallon for lubricating purposes. This sand is of interest because it is the same as that in which oil was discovered in 1860. Along Buell's run, one mile southwest of Elba, is a sand which is reported to lie from 15 to 35 feet below the 140-foot. It is said to have been first struck in 1888 on the land of Thomas Marshall, in the southwest corner of section 21. This well started at 100 barrels. Some experienced drillers, however, regard this sand as the 140-foot. West of Warner a number of small wells have been secured in the Schramm sand, which lies about 140 feet below the Macksburg 500. This sand, which was discovered about 12 years ago, has never been an important producer.

The Third Stage in the Development of the Field.—The method of drilling, casing and tubing the early Berea wells has already been stated, and it has been shown how these failed to secure all the oil in the sand. Unfortunately this necessitated re-drilling the Berea territory at a great expense, and this is here considered the third stage in the development of the field. The first of these "second crop" wells as they are called, is reported by C. G. Dutton, of Elba, to have been drilled about 1895 by George T. McDonald on the old Phelps farm, two miles east from Macksburg. This well started at 75 barrels and in 1900 was producing five. It seems probable, however, that the start of the re-drilling was earlier, and O. C. Williams, of Macksburg, reports that the first well was drilled on the Atkinson farm about 1890, and in view of the large number of wells now drilled this date seems the more probable.

The wells are drilled dry, i. e. the water is excluded by casing which extends through the Salt sand. The territory has not been completely drilled over, but is approaching that state, and the number of wells is said to be as great as when the territory was drilled the first time. As might be surmised, the wells are smaller than those drilled in the eighties. The great body started at from 4 to 50 barrels, while formerly their initial production ranged from 10 to 400. The first drilling exhausted the gas, so that while the wells then flowed, they now have to be pumped.

This field is cited by those who believe that oil is now being produced in the earth's interior as corroborating that view. As a matter of fact it proves no such thing. The oil now being secured in the Berea was there when the territory was drilled the first time. The re-drilling is merely a result of the unfortunate methods in vogue a decade ago, and it is safe to say that when the existing Berea wells cease to produce, the life of the field will end.

Geology of the Field.—The surface rocks lie principally in the Monongahela formation or the Upper Productive Coal Measures. The Pittsburg coal, which here is little more than a black streak, is shown in nearly every hill. The limestone overlying it is more conspicuous. The Meigs Creek or as it is locally known the Macksburg coal, however, which lies about 80 feet above the seam previously named is important. It supplies the surrounding country with fuel, and was formerly mined at Macksburg for railroad shipment. Topographically considered the country is one of the most rugged parts of the state. The succession underground is shown by the following well records:

Dunn well No. 6, northeast quarter section 12, Jackson township, Noble county. Completed March, 1891. Log furnished Survey by Orton Dunn. Surface of the well six feet below the Meigs Creek coal.

	Thickness of stratum. Feet.	Total thickness. Feet.
Unrecorded	285	285
<i>Ames limestone</i>	1	286
Unrecorded	99	385
<i>140-Foot sand</i>	5	390
Coal	1	391
Red rock	20	411
<i>Cambridge limestone (Rucker lime)...</i>	4	415
Slate	39	454
<i>Limestone (case through).....</i>	8	460
Pale Green slate.....	35	495
Black slate	35	530
<i>Dunkard sand</i>	95	625
Coal	4	629

	Thickness of stratum. Feet.	Total thickness. Feet.
Slate	15	644
Peaker sand	25	669
Coal	1	670
Slate	32	702
500-Foot sand	22	724
Coal	3½	727½
Slate	20	747½

The interval between the Ames limestone and the 140-foot or First Cow Run sand is a little larger than that found farther west in Morgan county, and the same is true with reference to this sand and the underlying Cambridge limestone.

The following log of George Rice well No. 18, at Macksburg, is taken from Prof. White's report:¹

	Thickness of stratum. Feet.	Total thickness. Feet.
Conductor	10	10
Coal, Macksburg, (Meigs Creek)	5	15
Soapstone	8	23
Sandy shale	117	140
Limestone, blue	13	153
Slate, blue	10	163
Limestone, blue	12	175
Slate, blue	45	220
Red "cave" { red rock..... 10 feet blue slate..... 7 feet red slate..... 18 feet }	35	255
Slate, blue	15	270
Slate, red	7	277
Slate, blue	38	315
Limestone, blue	28	343
Sand ("140-foot sand" "First Cow Run")	35	378
Slate, blue	32	410
Slate, black	10	420
Slate, blue	5	425
Slate, red	27	452
Slate, blue (cased)	4	456
Limestone	14	470
Slate	72	542
Limestone (water)	12	554
Sand ("300-foot sand, Dunkard")	78	632
Slate	53	685
Sand (500-foot sand)	17	702
Slate	39	741
Sand	9	750
Limestone	25	775

¹West Va. Geol. Sur. Vol. 1, p. 298.

	Thickness of stratum. Feet.	Total thickness. Feet.
<i>Sand, pebbly (800-foot sand).....</i>	51	826
<i>Slate</i>	79	905
<i>"Salt sand"</i> { <i>Sand, hard..... 68 ft.</i> <i>Slate, black 54 ft.</i> <i>Sandstone, hard</i> <i>white 68 ft.</i> }	190	1,095
<i>Slate, dark</i>	21	1,116
<i>Sand, dark, pebbly (Salt-sand and "Big Injun")</i>	214	1,330
<i>Slate, light, black at bottom.....</i>	293	1,623
<i>Slate, black</i>	11	1,634
<i>Shells and black slate.....</i>	44	1,678
<i>Macksburg (Berea) oil rock.....</i>	17	1,695

Commenting on this record Professor White says: "The sand at 1,116 feet is the one which was always known as the 'Salt sand' by the Macksburg operators, but its upper half only belongs in the West Virginia operators 'Salt sand,' while its lower half is the Big Injun, the Mountain limestone usually separating them, having thinned away and permitted the two distinct formations to combine practically into one rock.

"Whether the sand at 685 feet or that at 775 represents the 'Second Cow Run is not known certainly, but more probably the latter."

If Professor White is correct in the opinion expressed in the last paragraph, the 500-foot sand and the Second Cow Run are not equivalent, but the latter lies 90 feet below the former. It will be noted that he regards the 800-foot sand as more probably the equivalent of the Second Cow Run. The interval between the First and Second Cow Run sands at Cow Run, where the deeper sand was named, is 400 feet. That at Macksburg, between the 140-foot or First Cow Run and the 500-foot sands is but little more than 300 feet, while that between the 140-foot and the 800-foot sands is almost 400 feet. These relations support Professor White's claims.

The Macksburg oil field is located on an anticline. On one side the strata dip rapidly westward, and the Meigs Creek coal seam, which at the village of Macksburg lies 200 feet above the valley, is found at water level along the Muskingum where it has long been mined. The point at which the coal reaches its highest altitude has not been determined, but it must be near Macksburg. To the east the dip is apparently smaller than to the west, so that for a distance of ten miles in Salem and Liberty townships the coal is well above drainage, and is mined for local consumption. In fact the limestone or Pittsburg coal which lies about 80 feet below the Meigs Creek is found at a number of points above drainage in Liberty township, and as far east as Flint's Mills, Ludlow township.

The Oil Sands.—Few oil fields have the number of producing sands that this one has. However, the greater number of them have been of little

importance. The succession is as follows in the valley of Duck Creek at Macksburg:

1. Shallow Oil sand (First sand worked).
2. 140-foot or First Cow Run sand.
3. Buell Run sand.
4. 300-foot sand = (?) Dunkard.
5. Peaker sand.
6. 500-foot sand.
7. Schramm sand = (?) 700-foot.
8. 800-foot sand = Second Cow Run.
9. Berea or Macksburg sand.

Sand No. 1 is of historic interest, since it was in this that the first oil was found in 1860. The formation is quite thin—5 to 6 feet—in the few wells in which it produces at present. It seems never to have produced beyond the valley of Duck Creek, and might well be termed a “stray”, to use the suggestive name of the driller.

Sand No. 2, or the 140-foot, is one of the best in the field. It was discovered very early and has been producing continuously, or nearly so, ever since. Its position is about 330 feet below the Macksburg or Meigs Creek coal, and nearly 100 feet below the Ames limestone.

Sand No. 3, or the Buell Run, is of very little interest, and is found on a few farms only, as has already been stated. In fact it may properly be classed with the “strays.”

Sand No. 4, or the 300-foot sand, is also of little interest. It has never been an important source of oil in this field. The sand may be the equivalent of the Dunkard of West Virginia.

Sand No. 5, or the Peaker, has yielded some oil in and around Macksburg. The first well in it was drilled on the Peaker lot, Macksburg, in 1877. It is said to have started at 40 barrels and to have produced 16 barrels per day for three months, and then decreased until 1879, when it was abandoned.

Sand No. 6, or the 500-foot, is one of the three important producers of the field. It lies about 730 feet below the Meigs Creek coal, and has a thickness that usually ranges from 10 to 30 feet in the producing territory. Normally it is a soft, porous sandstone, but sometimes runs into a conglomerate. It is more continuous in this field than the 140-foot sand, but occasionally disappears, its place being occupied by shales. As an oil producer it is long lived, but it cannot be said to surpass the 140-foot sand in this respect.

Sands No. 7 and 8 never have been, nor are they now, important producers. Many years ago they yielded some oil in the valley of Duck Creek, but were long unproductive until the Schramm sand was found near War-

ner about 12 years ago. The position of this corresponds closely with that of the 700-foot, and the two appear to be equivalent. Both Nos. 7 and 8 are ordinarily unrecognized by the driller. They appear to have a small area, and may properly be classed with the "strays."

The next and lowest of the sands in this field is the Berea, and it is the best known and most valuable sandstone stratum in the state. It underlies the entire eastern half of the state, and its character has been shown by the hundreds of wells drilled to it. Nowhere is it better known than in southeastern Ohio. It lies from 1,665 to 1,675 feet below the Meigs Creek coal, but eastward the interval appears to increase, being 1,688 feet on the old Phelps farm, two miles from the village. At Macksburg the sand in the valley is struck at a depth of 1,460 feet, but at Elba, two miles southeast, it is found at about 1,550 feet, indicating a strong dip in that direction. The sand ranges in thickness ordinarily from 7 to 25 feet, the average being perhaps 17 feet. Normally it is finer than the shallow sands, and is much more continuous. Rarely, in fact, does it disappear, and this character makes it a landmark among drillers.

DEVELOPMENT OF THE COW RUN FIELD.

Operations in this field, after the period of earliest development, were much less extensive than at Macksburg. The territory was never greatly extended beyond the narrow valley of Cow Run, and in 1900 the producing area was confined to the southern half of sections 14 and 20 and the northern half of sections 13 and 19 of Lawrence township. The territory almost joins the Newell's run field, and the two might be considered as one; nevertheless, because of the historic interest of the former, and as a matter of convenience, the two will be discussed separately.

The drilling of the Perkins well to the Second Cow Run sand in 1866 was of great importance, since it demonstrated the existence of a reservoir of oil in a deeper sand, thus increasing the production and extending the life of the field. This may be regarded the second stage in the development. The success of the Perkins well again filled the valley with excitement, and the scenes resembled those of a few years before. Another discovery of importance was made in 1869 when it was found that oil existed under the hills as well as the valley. This may be regarded as the third stage in the development of the field. From that year wells have been drilled from time to time until the present, and doubtless others will be occasionally drilled in the future.

The production down to 1885 is reported by Mr. Minshall as follows:

	Barrels.
1861-1867 estimated	50,000
1867-1868 (August)	150,000
1868-1869 West Va. Transportation Runs.....	89,571
1870 West Va. Transportation Runs.....	110,412
1871 " " " "	46,543

					Barrels.
1872	"	"	"	"	39,456
1873	"	"	"	"	35,016
1874	"	"	"	"	31,990
1875	"	"	"	"	26,606
1876	"	"	"	"	20,427
1877	"	"	"	"	21,461
1878	"	"	"	"	22,929
1879	"	"	"	"	22,370
1880	"	"	"	"	20,655
1881	"	"	"	"	16,994
1882	"	"	"	"	12,682
1883	"	"	"	"	14,166
1884	"	"	"	"	8,291
1885	Ohio Transit Co.				12,000
Total					751,519

Mr. Daniel Ward, who has resided in the territory since 1868, reports that the spring-pole method of drilling had been abandoned when he entered the valley. This crude plan was followed by the steam engine, which at first operated a string of tools weighing between 300 and 400 pounds, constituting a marked advance over the preceding method, but was slow in comparison with the present. A depth of 300 feet might be reached in 30 days, and with good luck the Second Cow Run sand might be struck in 40. There was usually but little trouble from water, but much from caving. This was prevented by casing the wells, the material being sheet-iron, of which the joints fitted together like stove-pipe. The worst cave was found in red shales lying above the first sand, and is probably the "Big red," which has already been referred to several times in this report.

There were formerly several famous wells in this field, but nearly all have long been abandoned. The following letter written by Judge L. W. Chamberlain, of Marietta, and published in the Marietta Register, June 15, 1899, discusses the School House well, perhaps the most interesting one of those now producing on Cow Run:

"There has been much written and printed recently in regard to early oil developments in Ohio and as might be expected, the writers have been at fault frequently in their statements. Recently quite a great deal has been written in regard to the School House well at Cow Run in this county. The history of that well is about as follows:

"In the summer of 1869 Moffit Dye and several others leased of the school board of Lawrence township about one-fourth of an acre owned on Cow Run and occupied by a hewed log school house, situated within 20 feet of the Run.

"Wells had been drilled all around the old school house, and the leasers proceeded to put down a well in front of the door of the old academy, and on the 21st day of October, 1869, the drill broke into a crevice at a depth of

594 feet, and gas and oil immediately came to the surface and drove the drillers out of the derrick. In that early period few wells about the Run had been cased with artesian casing and this was one of the few. The well continued to flow for about one year, during which time it had put out about \$63,000 worth of oil which had to be hauled to market, the school board securing one-third of this as royalty. At the end of one year the well was pumped and has continued to produce ever since, now nearly thirty years. The production ran down for many, but for several years has produced the same for each year. Until recently the well has been pumped by steam, but during the past year has been fitted up with a gas engine which is being run by the gas from the well and plenty to spare. The old casing is still doing duty in the well, and the well promises to yield for many years to come. Modern oil men claim, some of them, that there is no such thing as a crevice well, but there can be no doubt about this one being just what the drillers pronounced it in the start, a genuine crevice of about one foot opening. The well was never shot and has never required cleaning out.

"There are other wells on the Run that are older than this that are producing to-day."

According to Judge Chamberlain the well produced three barrels per day in 1900. It seems neither to increase nor decrease. The royalty from the well goes to the general educational fund of the township, and for years more than met expenses, the surplus being loaned. The royalty is a graded one depending on the production of the well; at first it was one-third, then one-fourth, and at present one-eighth.

The following companies were operating on Cow Run in 1900:

Exchange Oil Company
Bergen Oil Company
William Reeder
Ward & Campbell
Gilbert & Davis.

The Exchange Oil Company owns 501 acres and has long been active in the field. It had 28 producing wells which were about equally divided between the First and Second Cow Run sands. The wells were very small, making about 350 barrels per month. They were pumped every other day, and then only 3 hours.

The Bergen Oil Company had 10 wells, 4 of which were in the First and 6 in the Second sand. These made about 150 barrels per month. It is seen from this that the wells are all small. They were pumped for a short time each morning and evening.

The other companies named were very small producers. William Reeder had 5 wells, Gilbert and Davis 5 or 6, and Ward and Campbell 4, the latter's making perhaps 75 barrels per month.

In the summer of 1902 the property of the Exchange Oil Company was divided into 4 parts, and three of these were leased respectively to the Boston Oil Company, William Reeder and John Gray. In August the drill was once more put to work and it was expected that 30 wells would be drilled before the close of the year. The first wells were all small producers. They were located on the hill sides facing Cow Run and went to the First sand. These wells are located in territory that was once drilled. Not improbably the Second sand also will be tested, and it may be that the floor of the valley itself will be drilled over. Before this work began there were 26 wells making conjointly 9 barrels per day on the property.

From what has been said it is apparent that the field at present is of little importance. It will doubtless be a small producer for many years, but interest will center in its past record.

Geology of the Field.—The surface formations lie in the Cone-maugh, Monongahela and Dunkard series. Topographically the territory is very rugged. Fortunately three coal seams, The Hobson, Meigs Creek and Pomeroy, with their associated rocks, are all above drainage, and consequently it is easy to determine the structure of the region. This has long been known. It was discussed by Andrews in Volume II, pages 493-99, of the Ohio Survey, published in 1874, and by F. W. Minshall in Volume VI, Chapter VI, published in 1888. Since, however, neither of these volumes may be accessible to the reader, the essential points are reviewed here.

The Cow Run oil field lies on one of the greatest arches found in Ohio. In the central part of the field the Meigs Creek coal lies 245 feet above the bed of Cow Run, and the Pomeroy seam, 153 feet. Following these west along Cow Run, the Pomeroy coal falls below drainage in less than one-half mile, and the Meigs Creek in about one and one-half miles, just below the point at which Cow Run unites with the Little Muskingum. Going east from the centre of the oil pool, the strata, as shown by the coal beds, drop more than 200 feet in 2 miles. The same relations are found in going north and south from the centre of the uplift. Hence the strata make a dome from the centre of which the rocks dip in all directions.

The formations in the hills along Cow Run have been measured by Andrews and are here reproduced.¹

	Feet.	Inches.
Yellow shale	25	00
Coal, <i>Hobson seam</i>	1	4
Clay	0	4
Coal	0	8
Clay	1	0
Black bituminous slate	0	10
Coal	0	1

¹*Geol. Sur. of Ohio*, Vol. II, p. 496.

	Feet.	Inches.
Clay	0	3
Limestone	4	00
Not exposed	18	00
Heavy sandrock	60	00
Shale	10	00
<i>Coal, "Sandstone" or Cumberland seam</i>		
(not measured).		
Not exposed	75	00
Blue limestone	4	00
Buff limestone	2	00
Limestones and shales.....	10	00
<i>Coal, Pomeroy seam (not measured).</i>		
Not exposed	98	00
Blue limestone	5	00
Not exposed	40	00
<i>Bed of Cow Run.</i>		

The sandstone or Cumberland coal is what has already been referred to several times as the Meigs Creek.

The underground succession is shown by the following record of Centennial well No. 6, drilled in 1896, and located east of the centre of the uplift on property of the Exchange Oil Company. Data furnished by Mr. George Lehmer, Marietta, Ohio:

	Thickness of stratum. Feet.	Total depth. Feet.
Conductor	11	11
<i>Pittsburg (Pomeroy) Coal</i>	1	12
Calcareous shale	9	21
Lime	10	31
Red soapstone	5	36
Red shale	8	44
White shale	42	86
Lime	10	96
Mixed shale	5	101
Shale and water	19	120
Red shale	10	130
Sand	5	135
White shale	20	155
Red shale	22	177
White shale	23	200
Sand	3	203
Red rock	32	235
Sand	11	246
White slate	40	286
Sand	4	290
Sand	4	294
Coal, smut rock	1	295
White slate	4	299
Lime	8	307
Gray shale	2	309

	Thickness of stratum. Feet.	Total depth. Feet.
Lime	9	314
Fire clay	4	318
Lime	7	325
<i>First Cow Run Sand</i>	47	372
Red rock	23	395
White shale	46	441
Dark shale	50	491
Sand	10	501
White shale	14	515
Pale red shale, very hard	64	579
Lime	5	584
Sand	10	594
Black shale	16	610
White shale	30	640
Sand	10	650
Coal	1	651
Sand	39	690
Dark shale	5	695
Sand, gas	7	702
White shale	11	713
Coal, smut rock	1	714
Fire clay	20	734
Sand	2	736
Sandy shale	6	742
Black shale	4	746
Slate, black	30	776
<i>Second Cow Run Sand</i>	64	840
Black slate	3	843
Black slate	97	940
Sand	83	1,023
Dark shale	57	1,080
Sand	12	1,092
Black shale	53	1,145
<i>Salt sand</i> (no water)	9	1,154
Light shale	6	1,160
Black shale	23	1,183
<i>Big Injun sand</i>	2	1,185
Dark shale	39	1,224
Sand	2	1,226
Dark shale	7	1,233
Sand	7	1,240
Sandy shale, hard	22	1,262
Dark shale, hard	63	1,325
Dark shale, softer	20	1,345
Dark shale	20	1,365
Dark shale, hard	10	1,375

At this depth the well was abandoned because the hole had become crooked.

The thin seam of coal found 12 feet below the surface is the Pittsburgh. The interval between it and the First Cow Run sand is 313 feet, while at Macksburg it is 328 feet. At Macksburg the Salt-sand lies 527 feet below the 140-foot sand, while at Cow Run the interval as shown in the above record is 820 feet. If the sands here are correctly named it shows a rapid thickening of the section to the southeast. However, the stratum called Salt-sand is insignificant in comparison with that found at Macksburg, and it is quite certain that the heavy sand struck at 940 feet is the sand in question. This would make the interval 568 feet.

The Oil Sands.—As has already been said there are two producing sands, the interval between the two being about 400 feet. The upper or First sand frequently has a thickness ranging from 30 to 35 feet. The top is fine and hard, and hence contains little oil. Immediately below, the rock is coarser and softer and here the oil is found. Generally a few feet of limestone are reported above the oil rock, but examination of the material shows it to be a sand. The lower or Second sand is thicker than the upper one, ranging frequently from 40 to 60 feet, but figures above and below these are found. Sometimes the sand is divided by from 6 to 8 feet of slate, in which case the oil is found below the break. Generally the top of the rock is fine and hard, and frequently the pay lies immediately below. Outside of Cow run this formation is not easily recognized, and almost any sand lying from 100 to 500 feet below the First is called the Second by the driller.

OTHER WELLS IN LAWRENCE TOWNSHIP.

As might be expected the success along Cow run stimulated the driller in his search for oil in the surrounding territory, and as a result wells were drilled by the scores. While a small well has been found occasionally, the results have not compensated the operator for his time and money.

In the northeast corner of the township in section 6, several shallow wells have been drilled; of these 3 were dry and 2 produced some gas, but are now abandoned. In section 5, immediately to the south, 2 wells are reported—a dry hole in the northeast quarter and a small producer near the middle of the section. One failure is reported in the northwest corner of section 4.

On section 12, which joins 6 on the west, a half-dozen wells have been drilled, but since these belong to the small pool around Fifteen P. O. they will be considered in that connection. Three dry holes have been drilled in the southeast corner of section 18, which joins 12 on the west. Along the streams in sections 16, 17 and 23 probably two scores of wells have been drilled. A few small producers have been secured, enough to encourage the driller. Two of these wells were deep, one on the Rathbone farm 1650, and the other on the Britton 1800 feet. By far the

greater number went no deeper than the First Cow Run sand. In the northeast corner of section 2, two dry holes have been drilled. Farther south many dry holes and a few producers have been drilled along the valleys of the Little Muskingum and tributary streams in sections 15, 21, 27, 20, 26 and 25. Nearly all of these are in the First Cow Run sand, but occasionally a deeper one was drilled. Thus in the southeast corner of section 26 one reached a depth approximating 1700 feet. Along the eastern line of section 2 several wells have been drilled, but these form a part of the Bosworth pool, and will be considered in that connection. On section 1, three dry holes have been drilled along the north line, and 2 dry holes and 1 producer near the south line. In section 13 many wells have been sunk, but these are part of the Newell's Run field and will be considered when that pool is discussed. Three dry holes and 1 producer have been drilled on the southern half of section 19.

WELLS IN THE WESTERN HALF OF WASHINGTON COUNTY.

Having now considered the Macksburg and Cow Run fields, the western half of the county will be reviewed. Hereafter the pools will be taken up with reference to their geographical position, and independent of the time of their development.

Palmer Township.—Lying in the northwestern corner of this township there is part of one of the most valuable pools in this part of the state. It includes the territory near Brown's Mills and constitutes the eastern part of the Chester Hill field. Since this has already been considered in the chapter on Morgan county it will not be further noticed here. In the southeastern corner of this township and the adjacent part of Barlow a number of gas wells have been secured. The sand is shallow, though reported deeper than the First Cow Run. It is said that gas was formerly piped from this field. In 1902 one well was used for lease purposes and the others supplied farmers.

Barlow Township.—Besides the gas wells referred to above three pools of oil have recently been discovered. These all lie along the northern border of the township. The most promising territory is occupied by the Fisher farms on which oil was first secured in August, 1901. A year later 30 wells, 14 of which were producers, had been drilled in that vicinity. Not until the 12th well had been drilled was a good producer secured. This had an initial production of fifty barrels the first 24 hours, and made 35 barrels per day for some time. The best well is reported to have had an initial production of 125 barrels. The sand is the First Cow Run and its record in other fields for treachery is fully maintained here.

One mile southwest from the Fisher farm a pool has been opened on the Lynch tract. In August, 1902, only 4 wells had been drilled and one of these was dry. In the northwestern corner of the township a small pool has been secured. The wells are on the Woodruff, Arnold and Beck-

enridge farms. Like the preceding pool, however, sufficient work had not been done when the territory was visited to indicate the size of the field. The sand is the First Cow Run. Outside of these pools many wells have been drilled. Near Vincent several gas wells have been secured which supply the village with fuel. Several small oil wells also have been found in that vicinity. No considerable area remains untested, and yet small pools may still be found.

THE MOORE'S JUNCTION OIL FIELD.

Location and Area.—The principal part of this pool lies in the immediate vicinity of Moore's Junction, 3 miles southwest of Marietta. It extends directly out to the Ohio river, across which it is continued in West Virginia. It has a length of one and one-half miles parallel to the river, and a maximum extension at right angles to this of 1 mile. From the western side of this a narrow strip starts north 32 degrees west (as run by a surveyor) and extends without a break past Tunnel station to Turkey Hen creek in the northwest corner of Warren township. In fact about 2 miles beyond this, near the southern line of Watertown township on the Potmyer and adjacent farms, a few small producers have been secured, which may be a continuation of the narrow strip just referred to. Throughout parts of this the productive strip is so narrow that one row only of wells is drilled.

Discovery and Development.—The anticline which crosses the river at Moore's Junction has long been known. Because of its presence the late Dr. Edward Orton predicted that oil or gas would be found in that vicinity. This was before any wells had been drilled.

According to Colonel Moore, who owns the most valuable part of the pool, the first well was drilled in June, 1894, and was located on his farm along Chapin run, a short distance from the river. At a depth of 1130 feet a small amount of oil was secured, and as a result of this encouragement two additional wells were drilled the same year. However, the production was so small that the operators were not willing to make further tests, and it was not until 1898 that another well was drilled. This too, was a failure, but at about that time oil was found across the river, and this made certain further explorations on the Ohio side. The next well on the Moore farm started at 150 barrels per day, and at about the same time Barnsdale and Ranger who held the lease on the Wittekind farm, adjoining Moore's, struck the sand and were rewarded with an 80 barrel production.

A little later a well was drilled along the line of the Moore farm, close to the Wittekind well. It flowed 500 barrels the first 24 hours, but ruined the Wittekind, which at once dropped from 80 to 40 barrels, and decreased so rapidly that it was soon abandoned. From that time work has been continued on the Moore farm until at present (August, 1902) the rigging is up for the 65th well.

The second well on the Wittekind was drilled in November, 1898. It was small, starting at 20 barrels, but decreased rapidly and in July, 1900, was making about 1 barrel per day. Two additional wells were drilled on this farm the same fall, and one of these, No. 4, which was completed December 14th, flowed 37 barrels the first 30 minutes, and 74 barrels per hour during the following 48 hours. Then it flowed 60 barrels per hour for an equal length of time. Two weeks after completion it produced 300 barrels per day. The flow gradually diminished and by March, 1899, was 200 barrels per day. At that time another well was drilled about 300 feet northwest and the production in No. 4 dropped to 100 barrels. From that time the yield has steadily diminished, and in August, 1900, was only 10 barrels each 24 hours. Doubtless it is now still less.

Well No. 9 on the Wittekind farm was completed in April, 1899, and flowed 240 barrels the first 24 hours; it dropped to 120 barrels the second day, and the third day ceased flowing entirely, though some gas was given off. Later the well was pumped and produced from 4 to 5 barrels per day, a rate that was continued as late as August, 1900. In all 19 wells had been drilled on this farm of 148 acres at the date just mentioned; seven of these were producing oil, about 50 barrels in all per day; and one gas enough for the boiler which supplies the power necessary for pumping the wells. The farm was being operated by the United States Oil Company, which purchased it from Barnsdale and Ranger for a large sum. The producing sand was reported to be the First Cow Run.

The success of the Moore and Wittekind farms led to explorations in all directions. Along the east side of the latter tract an almost unbroken line of dry holes has been drilled, and the same is true of an east and west belt running through the Moore farm, so that the limits of the pool have already been determined. Westward, however, more favorable results have been secured. On the Cook farm adjoining the Moore, 15 wells have been drilled, 4 of which were failures. All are in the First Cow Run sand except one which has a depth of about 1300 feet and is reported to be in the Salt sand. The wells are now all small, the combined production being in August, 1900, about 25 barrels per day of 12 hours. Oil taken from the tank on this farm showed a gravity of $43\frac{1}{2}$ degrees B. Lying south of the Cook farm is the Rupert on which there were 7 producers, and 2 dry holes. Four of these are in the First Cow Run and the others were reported in the Macksburg 800-foot sand, the latter being found at about 1,100 feet. The Rupert farm is joined on the west by the Dye. On this 15 wells have been drilled, of which one produced gas and two were failures. The gas and one oil well have been abandoned, so that there were 11 producers which made 25 barrels per day. With the exception of the gas well all are in the First Cow Run sand. The last productive farm along the river is the Cone; on this 4 wells have been

drilled, two of which were dry and one produced some gas. The oil well was producing about 1 barrel per day when the place was visited.

The narrow strip running northwest from the farms now discussed presents nothing that requires special mention. The wells are all reported in the First Cow Run sand, and the depths support that statement. As a rule the wells are small; the best producer was drilled on the Charles Purdue farm near Tunnel station in September, 1894, and began flowing 500 barrels per day, but in August, 1900, produced only 4 barrels in 24 hours. The initial production of most wells is insignificant compared with this one. As has already been stated this strip is very narrow, and when it reaches Turkey Hen creek is not more than 200 feet in cross section.

The little pool on the Potmyer and adjacent farms was opened in 1892. The first well made a show of oil and gas, but was never pumped and has long been abandoned. The First Cow Run sand was reported at 645 feet, and made a show of oil; another sand, probably the Dunkard, was found between 700 and 800 feet, and a third called the Macksburg-800 at 1,145 feet. The contract, however, required that the driller should reach the Berea, and work did not cease until a depth reported at 2,200 feet had been attained. The same year a well having a similar depth was drilled on the Bohl farm, 2 miles north, but without success. About the same time a well was drilled on the H. C. and C. S. Benedict farm along Turkey Hen creek. It is reported to have gone to the Berea, and to have made a show of gas. In 1893 a well was drilled along the same creek on the Porter farm. A small production was secured in the First Cow Run sand at a depth of about 650 feet. From here drilling progressed southeast toward Tunnel station. No further work was done on the Potmyer farm until 1898, when a well starting at 25 barrels was secured in the First Cow Run sand. A small number of producers have been found on this and adjacent farms, but the wells are all small, the combined production being less than 20 barrels per day in the summer of 1900.

Geology of the Field.—The surface formations lie quite largely in the Dunkard series or Upper Barren Coal Measures, the Washington coal according to Prof. I. C. White being found about 50 feet above the valley at Moore's junction.¹ Outside of the principal valley the topography is very rugged, and naturally the depths of the wells vary greatly. The surface formations consist chiefly of sandstones and shales, and hence do not contain strata of the most value in stratigraphical determinations. As has already been said a low arch crosses the river near the junction. Its direction northwest has not been traced, but oil and gas are not found along this line for more than one mile. The narrow strip which runs northwest past Turkey Hen creek also has an arch at its southern terminus,

¹*Geol. Sur. of West Va.*, Vol. I, p. 288.

and this in all probability is found at all points along the territory. This arch is not conspicuous, and was detected by running levels from well to well.

No complete logs of wells were secured, and the following is taken from White's report to which reference has just been made. The well is No. 4, on Moore's farm, in the valley, a short distance from the Ohio river:

	Thickness of formation. Feet.	Total thickness. Feet.
Unrecorded	565	565
<i>First Cow Run Sand</i>	23	588
Unrecorded	157	745
Sand, some gas (Dunkard?)	100	845
Unrecorded	90	935
<i>Second Cow Run Sand</i> , strong gas	15	950
Unrecorded	92	1,042
<i>Macksburg 800-Foot sand</i> , some oil	61	1,103
Unrecorded	282	1,385
<i>Big Injun Sand</i> (water at 1,400 ft., filled up at 1,440 ft.), the bottom at.....	55	1,440

The thick sand struck at 745 feet, Professor White regards as the equivalent of the Cow Run or Dunkard sand of West Virginia. In other words the Cow Run sands of the two states are not stratigraphically equivalent—an important fact to remember. As has already been stated the First Cow Run sand in Ohio lies either on or a short distance above the Cambridge limestone in the Conemaugh formation or Lower Barren Coal Measures, while according to White, the Cow Run or Dunkard sand of West Virginia lies just above the Upper Freeport (No. 7) coal and hence makes the basal member of the Conemaugh formation.¹ This sand is known as the Mahoning, and in the Hocking Valley coal fields lies directly below or very close to the Cambridge limestone. Since in the well record just given the sand lies 157 feet below the First Cow Run it seems clear that it cannot be the equivalent of the Mahoning. In this state the latter formation is finely shown along the valley of Sunday Creek in Perry county, where it is quarried by the T. & O. C. R. R. Under cover, however, it loses its character, and is commonly replaced by shales in whole or in part, and so cannot ordinarily be recognized by the driller. The sand marked Second Cow Run is probably the Macksburg 500-foot, while that marked 800-foot appears to be the equivalent of the Second Cow Run.

The Oil Sand.—As has been stated there are three producing sands in this pool. The First Cow Run is normal, so that what has been said of it in other fields applies equally well here. Ten well records on the Moore farm show an average thickness of 23 feet, but in other places it is much

¹*Geol. Sur. of West Va.*, Vol. I, p. 201-2.

thinner, and not unfrequently disappears, its place being occupied by shales. Along Turkey Hen creek the sand lies about 100 feet below the "Big red" (shales) which is 85 feet thick, and below which a thin stratum of limestone has been reported. This may be the Ames or Crinoidal limestone. The "Big Red" is reported to be very persistent, and so is of considerable importance in stratigraphical work. The data at hand do not warrant any discussion of the deeper sands locally known as the Salt sand, Big Injun, Keener, etc. They are of little importance in this territory.

WELLS IN THE EASTERN HALF OF WASHINGTON COUNTY.

Marietta Township.—The existence of oil and gas at Macksburg and Cow Run, and in other parts of the country stimulated the citizens of Marietta to search for these fuels, and particularly for gas which was promising so much for those cities favored with a supply. The drill has descended not only to the Berea, but has passed through nearly 1,200 feet of the underlying Ohio shales. The search, however, was unsuccessful, and left little room to hope for a supply near the city.

The first well of which the Survey has secured record, was completed January 24, 1886, and was located near the eastern limit of the city. For information concerning this, and the following log, the Survey is indebted to Mr. Joseph Garry. The well was called the Brick Yard well:

	Thickness. Feet.	Total depth. Feet.
Red mud	30	30
Gray sand	6	36
Red rock, 90 ft. of 7½ in. casing.....	54	90
White sand	35	125
Red rock	40	165
Light slate	45	210
Dark gray sand	8	218
Red rock and white slate	102	320
Dark gray sand	7	327
White slate	48	375
Good white sand	25	400
Red rock and blue slate	120	520
Bastard Sand— <i>First Cow Run</i>	10	530
Blue slate	40	570
Red rock	25	595
Blue slate, show of coal	40	635
Black and blue slate.....	95	730
Bastard sand— <i>Dunkard?</i>	10	740
Blue slate	18	758
White sand, 783 ft. of 5½ in. casing....	25	783
White sand	67	850
Blue slate	75	925
Good white sand,		
show of oil { <i>Second</i> } ..	20	
Blue Slate { <i>Cow Run</i> } ..	30	
Sand and salt-water { } ..	25	1,000

	Thickness. Feet.	Total depth. Feet.
Blue slate	22	1,022
Coal	2	1,024
Light colored slate	76	1,100
Dark sand	5	1,105
Blue slate	35	1,140
Sand	10	1,150
Slate	10	1,160
Slate and shells	30	1,190
Sand	10	1,200
White slate	35	1,235
Slate and shells	23	1,258
<i>Salt sand</i> , little gas	145	1,403
Slate	6	1,409
<i>Big Injun sand</i>	145	1,554
Slate	231	1,785
Black slate	45	1,830
<i>Berea sand</i> (dry)	10	1,840
Slate and shells	163	2,003

However, in Pennsylvania large supplies of oil and gas are found in rocks below the Berea, and with hope of striking one of these another well was drilled which passed through nearly 1,300 feet of the underlying Ohio shales, but without finding an important sandstone stratum. The log of the Rake well below the Berea, which is taken from Dr. Orton's report, is as follows.¹ The well was begun March 18, 1886:

	Thickness of formation. Feet.	Total depth. Feet.
<i>Bottom of Macksburg sand (Berea)</i>		1685
Light slate and shells	28	1,713
Blue shale with slight changes in color, and hard sand	226	1,939
Soft brown sand	9	1,948
Slate and shells	94	2,042
Slate, no shells.....	16	2,058
Slate and shells	22	2,080
Brown sand	3	2,085
Sand and slate	5	2,090
Brown sand	5	2,095
Light slate	20	2,115
Slate and sand	5	2,120
Slate and sand	10	2,130
Slate	10	2,140
Slate and sand	28	2,168
Light slate	7	2,175
Slate	5	2,180
Slate and sand	8	2,188
Slate	7	2,195
Light slate	15	2,210

¹*Geol. Sur. of Ohio*, Vol. VI, p. 400.

	Thickness of formation. Feet.	Total depth. Feet.
Dark slate	27	2,237
Light slate	48	2,285
Dark slate	40	2,325
Light slate	80	2,405
Slate and sand	11	2,416
Slate	69	2,485
Slate and sand	10	2,495
Slate	15	2,510
Soft slate	55	2,565
Slate	55	2,620
Slate and shells	10	2,630
Slate	15	2,645
Black slate	95	2,740

In 1900 several wells were drilled for oil within or near the corporation limits. On the George Cisler tract of 20 acres, 8 wells were sunk, 3 of which were failures. The depths ranged from 430 to 495 feet. On the Jacob Gedell farm there were 3 producers and 2 dry holes, and a 6th well was being drilled when the territory was visited (July, 1900). Well No. 1 was completed in March, 1900, and started at 117 barrels. Its decrease was very rapid and on July 30th following, produced only 2 barrels per day. The sand in this well was 30 feet thick and the top lay 390 feet below the surface. Well No. 4, drilled early in June, 1900, flowed through the casing, producing 90 barrels daily, but like all the wells in this sand its decrease was very rapid, and by the close of the next month was yielding from 3 to 4 barrels only per day. These initial productions are very exceptional, the average being a small fraction of them. Wells have been drilled on adjacent tracts owned by Mash, Lawrence, Rathbone and Ellenwood, but the results have been discouraging. The position of this sand is reported immediately above the "Big Red," the latter lying about 90 feet above the First Cow Run sand. It is the equivalent of the sand found on the Mitchell farm about 2 miles east, and hence is generally known as the Mitchell sand. Oil taken from the Gedell tank showed a gravity of 43 degrees B. On the Headley farm lying one-half mile northeast of the tract just discussed, two small producers have been found at depths of 239 and 242 feet. This sand lies nearly 200 feet above the Mitchell, and is known as the Goose Run. A number of shallow wells have been drilled along Duck creek where it flows through the township, but no producers of importance have been found.

These wells were very short lived. Many were abandoned in the fall of 1900 and when the territory was re-visited two years later not a well was to be found.

The Goose Run Pool.—This was developed in 1899-1900, and lay in sections 11, 12, 17 and 18, immediately north of the Infirmary farm. Nearly 50 wells, of which one-half were dry, were drilled in this field.

The sand, which is known as the Goose Run, is found at a depth of 150 feet along the stream of the same name. It lies above the Mitchell sand as is shown in the following record of Reed well No. 4:

	Feet.
Goose Run sand, top	300
Goose Run sand, bottom	331
Mitchell sand, top	525
Mitchell sand, bottom	546

This makes the interval between the two 194 feet, though it is reported to drop as low as 169 feet.

The Goose Run sand may begin producing at a high rate, but invariably its decrease is rapid, and the life of the wells short. Thus one drilled on the William Covey farm in the spring of 1899 started at 100 barrels, but decreased very rapidly and in a year was abandoned. The remaining wells started much smaller, but their decline has been almost as rapid. In fact, when the field was re-visited in 1902, there was scarcely a well to be found.

The Mitchell Pool.—This lies immediately south of the Infirmary farm, and has a length of one mile, extending to the Little Muskingum river. It runs nearly due northwest and southeast. Nearly 50 wells, most of which were producers, had been drilled by August 1, 1900. The best well in the pool was struck on the Mitchell farm June 19, 1899, and started flowing 100 barrels per day, filling two 250 barrel tanks before it was tubed. One year later it was producing approximately 3 barrels per day. Other wells started smaller, but declined as rapidly, and no well in the pool can be relied on to produce more than 3 or 4 barrels per day a few weeks after it has been completed. The wells are all shot, the charges reaching 60 quarts. Oil taken from the tank on the Scott farm showed a gravity of 41 degrees B.

The sand is called the Mitchell. Its position with reference to the First Cow Run is shown by the following skeleton record of a well on the Cain farm:

	Feet.
Top of Mitchell sand at	415
Top of First Cow Run sand at	600
Top of Second Cow Run sand at	1,000

The Hendersho. Pool.—This lies west of the Little Muskingum in the angle made by it and the Ohio river. The principal farms are the Hendershot and Buel. The first successful well in this pool is reported to have been drilled on the Hendershot farm in 1896. In all 23 wells had been drilled on this farm, 9 of which were dry when it was visited in August, 1900. Of the producers 2 had been abandoned, and the remaining ones made approximately 33 barrels per day of 12 hours. The best

well on this farm started at 125 barrels. The sand, which is from 15 to 20 feet in thickness, is the First Cow Run, and lies about 650 feet below the surface. Near the river little salt-water is found, but farther back it causes considerable trouble.

On the old Buel farm 12 wells have been drilled, 2 of which were failures. The 7 oil wells are in the First Cow Run sand, but the gas well extends to a depth of 1,100 feet. Only 4 of these wells were producing in August, 1900.

The Sand Hill Pool.—This lies on the opposite side of the Little Muskingum river from the Mitchell and Hendershot pools. The central part of the territory is in sections 3 and 9, but a narrow strip runs south to within a half mile of the Ohio river, and another east into sections 33, 27 and 22 of Newport township. Thus, in a general way, the productive area is triangular in shape, and as will be shown later each side of the triangle lies in a different sand.

The first well in this pool was drilled in August, 1895, on the farm of John Riley in section 3. It started at 80 barrels, and at once drilling began in earnest. By August, 1900, about 75 wells had been drilled within a radius of one mile from the Riley farm. The wells in the strip running south from the center of the field are nearly all in the Mitchell sand, but occasionally one is found deeper. Thus on the West farm, one-half mile east from the mouth of the Little Muskingum, a gas well was struck at a depth approximating 1,100 feet. Ten weeks after drilling it is reported to have had a closed pressure of 450 pounds, and a flow of 1,000,000 cubic feet per day. The Mitchell sand is found on this farm at a depth ranging from 500 to 560 feet. The sand is fine, and is shot with from 40 to 80 quarts of nitroglycerine. The wells are small and have a settled production of about 2 barrels each per day.

On the Anna Alcock farm (now the Perkins) a well was drilled several years ago to a depth of 1,105 feet. In the top of the sand, struck at 1,042 feet, much gas was found. At 1,070 a break of 5 feet was struck, below which 30 feet of sand were found. After shooting the lower stratum with 100 quarts of nitroglycerine, a strong flow of oil, amounting to 100 barrels per day, was secured. This sand is regarded by the driller as the Second Cow Run, and its position appears to be about correct for that formation. On the Thorniley farm, lying just east of the Alcock, a 20 inch seam of coal was found 65 feet below the surface, and 466 feet deeper the Mitchell sand was struck.

The wells in the narrow strip running east from the centre of the field are nearly all in the First Cow Run sand. On the John Riley tract this sand is struck at depths ranging from 575 to 625 feet, depending on the surface altitude. This shows a rise eastward since on the lower land of the Hendershot farm, lying one and one-half miles west the sand is struck at about 645 feet. The rise between these two farms must be at

least 50 feet. Following the territory eastward into Newport township little change is noted. The productive area there is very narrow, not being more than one-eighth of a mile. The altitude is greater, and accordingly the wells deeper. Occasionally a producer is found in a sand other than the First Cow Run. Thus on the Close farm in the northwest corner of section 27, one well is in a shallower sand, and on the Conger farm in the same vicinity 2 additional shallow wells are found. The latter lie only about 90 feet above the Cow Run, and so cannot be classed with the Mitchell sand. The wells in this part of the Sand Hill pool are all small, and cannot be depended on for more than from 2 to 4 barrels per day, a few weeks after having been completed.

A number of wells have been sunk in the valley of the Ohio between the mouth of the Little Muskingum and the eastern boundary of Marietta township, but no important producers have been secured.

THE OIL POOLS IN NEWPORT TOWNSHIP.

This township lies east of Marietta and is bounded on the south by the Ohio river. It is an important producer of oil, having had over 300 wells in operation in 1900. There are 3 pools, and besides these a number of scattering wells along the Ohio river:

1. The Newell's Run Pool.
2. The Bosworth Pool.
3. The Sand Hill Pool. (See Marietta township.)

The Newell's Run Pool.—This is the most important one in the township, containing more than 175 producing wells. It is named from the West Fork of Newell's run which traverses the principal part of the territory. The productive area includes the whole or parts of sections 10, 11, 12, 18, 24 and 30 of Newport township, and 13 of Lawrence; the last section practically uniting the field with Cow Run, but for convenience the two are considered separately. The principal part of the field has a length of 4 miles, and extends west of north. It crosses Eight Mile run near Gracey P. O., along which a narrow strip extends west of south for a distance of 3 miles. The maximum width of the field is one mile, but throughout the larger part does not exceed one-half mile.

The first producing oil well in this pool was drilled on the land of John Berg along Eight Mile run in the spring of 1890. About one month after this well had been begun, the Boston Oil Company started a well at Gracey P. O. in the southwest corner of section 13, Lawrence township. It was decided to make this a test well, the objective point being the Berea. Progress was slow; the tools became fast several times; once the rig caught fire and was destroyed; other difficulties incidental to deep wells, prolonged the work, so that the well was not completed until the following November. The First Cow Run sand was reported at 585 feet, and from it there was a flow of oil. The Berea was struck at a depth

of 1,932 feet, and though only five feet thick contained much gas, the closed pressure being reported at 440 pounds. The fuel was used in developing the surrounding territory, and the well is still producing. The discovery of large supplies of gas made operating much easier, and drilling progressed rapidly. The limits of the field appear to be now pretty definitely determined, though doubtless a fair number of producers will yet be secured. In 1901 the Berea sand was tested, 3 wells having been sunk on the Stephens farm. The best well produced 20 barrels of oil the first day and one the next. All were soon abandoned. From well No. 28 on this farm the following data were taken:

	Feet.
First Cow Run sand at	505
Salt sand at	1,210
Berea at	1,848

Geology of the Field.—This is of interest since it lies on the Burning Springs anticlinal which crosses the Ohio near the mouth of Newell's Run, and is known on this side of the river as the Newell's run uplift. The arch must be given high rank among structures of this kind in Ohio. Its magnitude is shown by the fact that at Eureka, West Virginia, the Berea is found at a depth of 1,350 feet, while 4 miles southwest on the Palmer farm, a well drilled on the river bank at practically the same surface altitude found the sand 1,950 feet below the surface, showing a fall of 600 feet in that distance. Passing eastward the same conditions hold, only the crest of the arch having been crossed the strata dip to the east. Thus a little more than one mile east from the mouth of Newell's run, the wells on the Ohio side of the river strike the Berea at approximately 1,600 feet; while at St. Mary's, West Virginia, 3 miles east from Newell's run, the formation lies 1,900 feet below the surface.

The arch has long been known. It appears to have been described for the first time by Prof. E. B. Andrews in the *American Journal of Science* for July, 1861,¹ and subsequent reference is made to it by the same writer in his report on the *Geology of Washington county* published in 1874.² According to this geologist the arch crosses the river near the mouth of Conley run, which unites with the Ohio nearly 2 miles above Eureka. Hence, the Berea should be found there at a smaller depth than at Eureka. The First Cow Run sand is placed 200 feet below the surface in the Eureka well by Professor White, while according to Andrews it is actually above drainage at the mouth of Conley run. According to this the Berea should be found at a depth of not more than 1,150 feet at the latter place. The dip, then, between this point and St. Marys, 3 miles

¹*Am. Jour. Sci. and Arts*, Vol. XXXII, new series, pp. 85-93.

²*Geol. Sur. of Ohio*, Vol. II, pp. 501-505.

distant, is 850 feet, making the eastern slope of the arch much steeper than the western one, as Andrews claims. It should be noted, however, that the dip on the western slope has not been measured at right angles to the direction of the uplift, which is nearly north and south, but at a smaller angle than 90 degrees, and consequently the dip stated is less than the real one on this slope. On the east side the measurement has been made on a line approximately at right angles to the line of uplift.

After entering Ohio the arch flattens and is soon lost, while in West Virginia, according to Andrews, it becomes more prominent, attaining a maximum near Petroleum, Wirt county.

In his report on Washington county, already referred to, Andrews gives a section at the mouth of Conley run, the top of which he considers the Cambridge limestone. Forty feet lower is a coarse sandstone which he calls the First Cow Run. The section is as follows:

	Feet.	Inches.
Fossiliferous limestone (Cambridge)	1	6
Yellow shales	18	0
Slaty coal	0	8
Clay and coal	0	6
Fire clay, light colored	0	6
Coal	0	6
Not exposed	20	0
<i>Sandrock, First Cow Run</i>	25	0
Iron ore, adhering to sandrock	0	6
Blue clay shale, with modules of iron ore ...	1	6
<i>Level of water Ohio river.</i>		

The limestone, however, is the Ames and not the Cambridge, and hence the sand below cannot be the First Cow Run. The limestone has all the characters of the same formation farther west and there can be no reasonable doubt as to the correctness of its identification. Its presence above drainage appears all the more remarkable when it is considered that westward it is not found above cover nearer than the valley of Federal creek in the western part of Morgan county. The distance between these two exposures is about 40 miles. Since this limestone is found above drainage along Conley run, it follows that both the Meigs Creek and Pomeroy coals are due in the adjacent hills. The seams are found at their proper positions, but both are small and unimportant.

It is of interest to note that the Newell's run pool lies on the western slope of the axis, and as will be shown later, the Bosworth pool on the eastern slope, the crest of the axis being unproductive, if the holes thus far drilled can be relied on.

The wells are all small. Even when they start at from 10 to 25 barrels or more per day, they soon decrease so that their output is a small fraction only of their initial production. However, after their settled pro-

duction is reached they continue without important change for years. The data already given illustrating the life of wells in the Joy, Buck Run and Cow Run fields show the staying quality of the sand, and there is no reason why the records in those pools should not be duplicated here. Below the production of a few farms is given (August, 1900). They have been selected at random and represent very well the average for the field:

Noland, section 11, 11 producers, 30 barrels per day.

Reese, section 11, 21 producers, 50 barrels per day.

Gracey, section 13, 15 producers, 20 barrels per day.

Hall, section 12, 22 producers, 25 barrels per day.

From these farms it appears that the average production of the wells is less than 2 barrels per day. The daily output of the entire pool was about 300 barrels at the date above mentioned.

The Productive Sands.—There are 4 of these: (1) The First Cow Run, (2) The Priest, (3) The Salt sand, and (4) The Berea. Besides these a well or two is reported in the Second Cow Run, but as will be shown later this cannot be the true sand bearing that name.

The First Cow Run sand is the only large producer in the field. It is found at a depth of 300 feet along the run on the Noland farm in section 11, and at 478 feet in the bed of Eight Mile Run in the northwest quarter of section 18. The sand appears in all respects normal.

The Second Cow Run sand is placed by the driller about 180 feet below the first sand, and this in those parts of the field nearest Cow Run, where it will be remembered the interval between the sands is 400 feet. It scarcely needs be stated that the sand in question cannot be the true Second Cow Run. Its position corresponds more closely with that of the Dunkard sand of the West Virginia survey,

The Priest sand supplies a few wells on Eight Mile Run in sections 24 and 30. It is reported to lie 150 below the Second Cow Run, so called. Its position with reference to the First sand, however, strongly suggests that it is nothing more than the Second Cow Run sand.

The wells in the Salt sand are as follows: 2 (both dry) on the Becker farm in section 30 along Eight Mile Run; 3 producers and 5 dry holes on the William Mendenhall farm in sections 24 of Newport, and 19 of Lawrence townships, the sand being struck along Eight Mile Run at a depth of almost 1,100 feet; 3 wells on the Berg farm in section 24, at a depth of 1,110 feet in the bed of the run. The wells in this sand have been of little commercial value. Those on the Berg farm are reported to have had a settled production each of 10 barrels per day. But one of them has been abandoned, and the remaining 2 produce conjointly 2 barrels only per day. The sand is reported to be quite free from water.

The Berea wells are as follows: One at a depth of more than 1,800 feet on the Reese farm in the northwest quarter of section 11, making a showing of oil; a strong gas well (already reported) at a depth of 1,932 feet at Gracey P. O.; two on the Becker farm in section 30, the sand having been found at a depth of 1,725 feet in the bed of Eight Mile Run; a dry hole on the Mendenhall farm in section 24; a gas well on the Berg farm in the northwest quarter of section 18. It is plain that the Berea is not an oil sand in this field. It produces, however, some gas—a great boon to the operator in a district without coal.

THE WELLS IN INDEPENDENCE TOWNSHIP.

This township lies north of Newport, and contains two pools: (1) Archer's Fork; (2) Elk Run. The two are closely related in every respect, but are considered separately in this report as a matter of convenience. Topographically considered the township is very rugged. The valleys are narrow, and the hillsides unfertile, so that the oil has proved of more than ordinary help to the residents.

Archer's Fork Pool.—This lies in sections 32, 33 and 27, and includes a small part of section 2 of Lawrence township. The length of the field is 2 miles, and the width does not appear to exceed one-half mile. The oil sand runs 40 degrees east of north. The pool is said to have been discovered 10 or 11 years ago when wells were drilled on the Davis and Ward farms. From that date drilling has been quite active until 1900. The wells are nearly all in the Berea, which appears normal, and is found on Archer's Fork at a depth of 1,780 feet. Occasionally a little oil is found in the First Cow Run and the Big Injun sands, the latter lying 380 feet above the Berea. Considerable gas is sometimes found in a sand called the Second Cow Run. The wells at first contain sufficient gas to flow the oil, but the older ones have to be pumped. The number of producing wells in this pool in August, 1900, was less than 50.

The Elk Pool Run.—This lies north of the last named pool, and includes a part of sections 29, 35, 30 and 24. As developed in 1900 its length was 2 miles, and its width three-fourths of a mile. The first producing well in the pool was drilled on the Mary Smith farm in the spring of 1898, and work was active until the close of 1900. Comparatively few dry holes have been drilled thus far, but the great depth of the wells and the small settled production have had a discouraging effect, so that very little work has been done since 1900.

The producing sand is the Berea, and is reached at depths ranging from 2,000 to 2,200 or more feet. However, a showing of oil is made in the Big Injun, Keener, Maxton and other sands. The succession of these sands is shown by the following skeleton section of a well on the Mead farm, furnished the Survey by W. T. Hastings:

Coal	{	top at 400 feet bottom at 402½ feet
Salt sand	{	top at 1,200 feet bottom at 1,280 feet
Maxton	{	top at 1,450 feet bottom at 1,500 feet
Mountain limestone	{	top at 1,510 feet bottom at 1,545 feet
Keener sand	{	top at 1,560 feet bottom at 1,615 feet
Big Injun and Squaw sand	{	top at 1,615 feet bottom at 1,730 feet
Berea sand	{	top at 2,124 feet bottom at 2,138 feet.

Other records provided the Survey by the same operator duplicate the one given, so that this may be regarded normal for the territory. The section contains several formations new to this report, and these will be reviewed here in order that what follows may be more clearly understood.

The great "key rock" by which the driller determines his position stratigraphically in this part of the field is the Mountain limestone, or the "Big lime" as it is commonly called. Its thickness in this pool commonly ranges from 35 to 50 feet. Westward it thins and does not appear at all in the Marietta and Macksburg sections. The farthest point west at which the writer found it reported is at Fifteen P. O. in section 7 of Liberty township, where it ranges in thickness from 0 to 20 feet. East from this place it is always present, making a datum plane of unusual value to the driller.

Resting either directly on this or separated from it by a few feet of shales is frequently found a sand rock which produces some oil, and is called the Maxton.

Immediately below the "Big lime" is a series of sandstones and shales known collectively as the Big Injun in which large quantities of oil are found in several pools. Occasionally, however, the formation consists of an unbroken sandrock from top to bottom. The upper part of the formation when separated from the lower by a few feet of shales is known as the Keener sand, named from the Keener farm near Sistersville, West Virginia. The succession there according to Professor White is as follows:

Big Lime (Mountain).

<i>Big Injun</i>	{	<i>Keener sand</i>30 ft.	125 feet.
		"Break" (slate).....15 "	
		Sand.....80 "	

In some cases an oil sand is found below the body of the Big Injun from which it is separated by a few feet of shales. This sand is called the "Squaw," a term used by the driller in about the same sense as the "stray."

West of Independence township the Big Injun is not a producer of oil or gas. In fact in the central part of the county it is not well marked, being there confused with the Salt sand. Eastward, however, where the "Big lime" is found its separation from the Salt sand is easy, and its identification certain.

The Berea in the Elk Run field ranges in thickness from 0 to 20 feet or more. The sand varies considerably. Sometimes it is coarse, porous and soft, and at other times fine and hard. Above and below it is succeeded by a dark shale. The sand contains but little water.

The largest producer in the field is reported to have started at 800 barrels. It was drilled early in 1899, and in August, 1900, was producing 40 barrels daily. Ordinarily the initial production of the wells was about 40 barrels per day. At first the wells flowed, but the gas pressure soon dropped so low that they had to be pumped. The oil has a density of 51 degrees B. The number of producing wells in the field in August, 1900, was about 65. The wells are shot with heavy charges of nitroglycerine, usually from 80 to 90 quarts. The sand, however, clogs rapidly, and then the wells are shot a second time. This process may be repeated later.

Other Wells in the Township.—The number of wells drilled outside of the two pools is not large, and nearly all have been failures. The record is as follows: A dry hole on the Ward farm along the western line of section 35; a dry hole on the Miller farm along the south line of section 18; 3 dry holes on the Hanlon farm, which joins the Miller; one dry hole on the Patterson farm along the south line of section 23, but a half mile farther south on the Hall land near the middle of section 22 a fine gas well has been secured; a dry hole on the Cady farm in the northeast quarter of the same section; one dry hole on the McKnight farm in section 10, and one on the Deucher farm in section 21.

On Leith run in the southeastern corner of the township, 9 wells have been drilled, only 3 of which were producers. A good gas well was struck at a depth of 1,100 feet on the Kiger farm. The remaining wells are in a shallow sand, struck at about 300 feet. On the Farnsworth tract in section 9 a small producer, now abandoned, was secured in a shallow sand, and a second well is being drilled (1900). On the Valentine farm in section 24 one dry hole has been drilled, and one mile southwest on the Bosworth farm in section 23 a gas well, now abandoned.

WELLS IN LUDLOW TOWNSHIP.

This township lies north of Independence, and extends to the Monroe county line. The Little Muskingum river flows zigzag fashion through

the township from the northeast to the southwest corners. The valley is very deep and hence strata are exposed that otherwise would not be seen. On Wingett's run in the northwest corner of the township Andrews has reported both the Meigs Creek and Pomeroy coal seams, the interval between the two being 94 feet. Both have been mined in that locality, but they are small and consequently unimportant. At Flint's Mills, in the southeast corner of section 21, the Pomeroy coal was formerly mined for local consumption. The seam is on a level with the river valley, and is covered with several strata of limestone. There are three pools of oil and one reservoir of gas in this township. All lie in the same vicinity, and might be considered as one. These are:

1. Hohman (oil).
2. Wilson Run (oil).
3. Flint's Mills (oil).
4. Wingett P. O. (gas).

Hohman Pool.—As developed in 1900, this consisted of an area of approximately one square mile, including parts of sections 7, 8, 13, 14. The first well is reported to have been drilled in 1896 on the DeLong farm, in section 7. It yielded a heavy flow of gas, and is now in control of the Carter Oil Company, which uses it as fuel in drilling and pumping. Work has been actively in progress from that time until the close of 1900. The number of producing wells in August of that year was 20. The oil is derived chiefly from the "Squaw" sand, the Berea being a small producer. The following generalized section of the sands is interesting:

	Feet.
Maxton sand	10-15
"Big lime"	40-90
Big Injun sand {	
Keener sand	10-15
Big Injun proper..	100-120
Squaw sand	8-35
	118-170

The "Squaw" sand is separated from the heavy ledge of sand above by from 2-15 feet of slate. The wells usually begin at from 25 to 50 barrels daily, and maintain the initial ratio fairly steady. Thus a well drilled on the Cross farm in April, 1900, starting at 30 barrels, was producing 20 barrels daily the following August. The wells are shot with from 40 to 120 quarts of nitro-glycerine, the size of the shot depending on the hardness and thickness of the sand. The oil from the "Squaw" sand has a gravity of 44½ deg. B. The Berea is finer and harder than the "Squaw." Its thickness ranges from 7 to 12 feet, but in one well the sand was absent, its place being occupied by shales.

The Wilson Run Pool.—This lies north of the Hohman and includes parts of sections 3, 4, 9 and 10. Northward it extends into Monroe

county, where it is known as the Rhinard's Mills pool. The principal part of the territory extends nearly north and south, and has a width ranging from one-quarter to one mile or more. Throughout much of the area the Little Muskingum river flows, its deep valley diminishing by two or three hundred feet the distance to be drilled. The pool is reported to have been first struck on the Beaver farm 7 or 8 years ago, though active work did not begin until 1897, when a 500-barrel well was secured on the Edwards tract in the southwest corner of section 4. The greater number of the wells, however, were drilled in 1899. The number of producers in August, 1900, was nearly 80.

The oil is found in the Big Injun and Berea sands. With two or three exceptions the wells on the east side of the river are in the former, while more than half of those on the west side are in the Berea. The Big Injun sand is reported to be from 65 to 70 feet ordinarily in thickness. The oil is found in the upper half of the rock, the pay streak ranging from 6 to 8 feet in thickness. Along the river in section 4 the Big Injun is found at a depth of 1,375 feet, and the Berea at 1,880. The drillers claim to recognize the Keener sand, and report it separated from the "Big lime" above by a few feet of shale, and from the sandstone below by from 1 to 6 feet of the same material. Its thickness is given at 40 feet. The Berea commonly ranges from 5 to 10 feet in thickness, but sometimes disappears, its place being occupied by shales or shaley sandstone. When the wells are shot the first time the charge is small, usually about 20 quarts, but as the wells are shot a second or third time the charge is larger. At first the oil flows, but the gas pressure soon falls so low that the wells require pumping.

The Flint's Mills Pool.—This lies along the Little Muskingum river in sections 15, 16, 22, 21, 20 and 26. At first the work was largely confined to the valleys, but more recently it has extended over the hills. The length of the pool as developed in 1902 was 3 miles, and the greatest width one and one-quarter miles. As has already been stated, the Pittsburgh or Pomeroy coal is exposed in the valley at Flint's Mills.

The first well in the pool is reported to have been drilled on the McLain farm in June, 1898. It extends to the Berea, and began producing 7 barrels daily, but two years later its production had decreased to one and one-half barrels. From that time work has been in progress; more than 100 wells having been drilled, of which approximately 90 per cent. were producers. The largest one thus far secured is on the C. & S. Graham farm, in section 20. It is reported to have started at 480 barrels, and to have produced 250 barrels per day for some time. Several months after completion it was still producing 150 barrels per day. This is one of the best wells yet drilled in southeastern Ohio. A well on the Elizabeth Smith farm, in section 21, drilled in December, 1899, and shot with 40 quarts of nitro-glycerine, started at from 8 to 10 barrels, and maintained

this rate for 2 or 3 months. It was then shot with 40 quarts and its production increased to 110 barrels. Later it was again shot, this time with 80 quarts, and the production increased. On August 14, 1900, it was shot with 40 quarts, the production starting at from 50 to 60 barrels per day. Nearly all the wells in the pool are in the Big Injun, an occasional one only reaching the Berea. The succession of sands is shown by the following skeleton sections:

Well No. 7, Watson Brothers' farm, located on bank of river, the top being at the horizon of the Pomeroy coal:

	Feet.
Cow Run sand at	500
Salt sand at	600
Maxton sand at	1,000
Big Injun sand at	1,400

Lucas farm, Well No. 1, data furnished by R. W. McConnell:

	Feet.
Cow Run sand at	580
Salt sand at	680
Maxton sand at	945
Big Lime at	1,181
Big Injun sand at	1,331
Berea at	1,823

The sand reported to be the Cow Run cannot be that sand, however. The interval between the First Cow Run sand and the Pomeroy coal at Macksburg is approximately 240 feet, while here it is reported to be 500 feet. The position of this sand with reference to the coal corresponds closely with that of the Dunkard sand in the Macksburg field.

There are 2 pay streaks in the Big Injun; one at the top, which usually produces some gas; the second lies 40 feet deeper and yields oil. The latter is from 4 to 6 feet thick, and is loose and pebbly. Occasionally, however, it is fine and hard, and then is dry. At first the larger wells flow, but the gas pressure soon falls so low that they require pumping.

The Wingett P. O. Gas Wells.—In the western half of sections 31 and 32 of Ludlow township, and the eastern half of sections 1 and 2 of Liberty township is a small but valuable reservoir of gas. The wells are all in the Berea sand. The first one drilled was in 1895 on the McCurdy farm, in the southwest corner of section 32. Its initial closed pressure was 850 pounds, but 2 years later, according to reliable persons, was 950 pounds per square inch. The well is located on the bank of the Little Muskingum, and reached the Berea at a depth of 1,687 feet. The well is the property of the Keystone Oil Company, and is used to supply fuel for drilling and pumping. The 6 remaining wells in the field belong

to the Carter Oil Company, and are used for a purpose similar to the well just mentioned. These had an initial rock pressure of from 750 to 900 pounds per square inch.

OIL WELLS IN GRAND VIEW TOWNSHIP.

This territory lies east of Ludlow and Independence townships. It is bounded on the north by Monroe county and on the south by the Ohio river. The topography is very rugged. Thus far the only oil found has been at two points along the river, one in the extreme southwestern corner, and the other in the northeast corner; the latter, however, forms part of the Sistersville pool, and so will not be considered in this place.

The Sheets Run Pool.—This lies in sections 22, 27 and 33. About 25 wells have been drilled in it, only 3 of which were dry. The best territory is on the Alonzo T. Dye farm. A well on this tract, drilled in 1896, started at 600 barrels per day, and produced 16,000 barrels the first year. By the close of that period the yield having decreased to 2 barrels, the well was shot with 6 quarts of nitro-glycerine, the production increasing to 125 barrels daily. On October 3, 1898, it was shot a second time, the charge being 10 quarts, with satisfactory results. The well was shot again March 31, 1899, with 40 quarts, and the production increased. On December 7, 1899, it was shot with 100 quarts, but the result was not beneficial. In the summer of 1900 the well was not pumped, but the proprietor expected to put it in condition again with the expectation of further production. It is claimed that the total yield of the well has been approximately 25,000 barrels. The sand from which the oil was procured is not definitely known, but it is said to be either the base of the Keener or the top of the Big Injun.

Nineteen feet above the place at which the oil was secured a heavy flow of gas was found, which blew the sand from the hole, and made further work difficult.

The wells on the north side of the place are in the Big Injun, and the 2 on the south side near the river are reported in the Maxton. The remaining wells, with one exception, are in either the Salt sand, Maxton or Big Injun. The well excepted is in a shallow sand. A well on the Riggs farm found the Berea at a depth of approximately 1,700 feet, but it gave no sign of oil.

Other Wells in the Township.—A number of wells have been drilled along the Ohio river between Sheets run and Matamoras. On the Beaver farm in section 28 a good gas well was secured in the Salt sand. The rock pressure is reported to have risen to 300 pounds in one minute after the guage was applied, and to have stood finally at 350 pounds. On the McMahan farm, east of the Beaver, 2 dry holes have been drilled, and another well was being put down when the territory was visited (1900). On the Cochran farm, in section 23, seven wells have been drilled. Of

these, 3 were dry, and of the producers one has been abandoned. They are in the Big Injun sand, and all are small. The Mountain limestone is reported having a thickness of from 80 to 120 feet.

Other failures in the township are as follows: One on the Collins farm, in section 24, and one on an adjoining farm, in section 18; one on the Williamson farm, on the south side of section 19; one on the Kraft farm, in section 8; one on the Grimes farm, along the west line of section 14; one on the Porter farm, in the northeast quarter of section 32; one on the Early farm, on the east line of section 15. A gas well is reported on the Algae farm, in the southeast quarter of section 28.

OIL WELLS IN LIBERTY TOWNSHIP.

The Germantown Pool.—Several years ago a gas well was drilled on the Miller farm, near the village of Germantown. Encouraged by the result, another well was drilled on the farm in 1901, and a small oil well was secured. Other wells were drilled, and by 1902 quite a pool had been opened. The best producer started at 80 barrels and at the end of the first month was producing 40. The top of the sand lies 790 feet below the Pittsburg coal, and hence appears to be the equivalent of the Second Cow Run.

Considerable drilling has been done in the vicinity of Fifteen P. O. and a small pool secured.

The oil is derived chiefly from the Maxton sand, which lies immediately above the "Big lime." The latter has a thickness in this territory ranging from 0 to 20 feet, and has not been found by the writer farther west. Eastward, however, it is reported in every well that is sufficiently deep. Occasionally a small production is secured in a shallow sand, reported to be the First Cow Run. The best producers drilled in 1895, started at from 25 to 40 barrels, but are now very small.

Near the village of Dalzell, in section 22, two dry holes have been drilled. One is reported to have reached a depth of more than 1,100 feet, and the other 1,840 feet. Quite recently a small well was secured in the Big Injun in the northern part of section 1, near the Wingett P. O. gas wells.

WELLS IN SALEM TOWNSHIP.

This lies south of Aurelius township, and the wells in the northern part form a portion of the Macksburg field. The territory is traversed from north to south by Duck creek. There are no important pools in the township, but considerable drilling has been done.

Along Pawpaw creek, near Bonn P. O., more than 30 wells have been sunk, some of them many years ago. The recent work was begun about 1896. Only 5 of the wells were producing in August, 1900, and these made conjointly from 5 to 7 barrels per day. The sand is shallow, lying approximately 450 feet below the Meigs Creek coal.

The most terrible accident ever known in the oil territory of south-eastern Ohio occurred in this field. In the spring of 1900 a well had been drilled on the Kelley farm and a charge of nitro-glycerine lowered to the bottom. The "go-devil" failed to discharge the shot; and then a "squib" containing about one-quarter of a pint of the same explosive, to which was attached a three-minute fuse, was dropped in the hole. This was followed by the discharge of the glycerine in the bottom of the well, and the spectators, thinking the action regular, ran to the derrick as soon as the eruption ceased. They had scarcely reached that place when there was another explosion, and 7 men were killed outright or so severely wounded that they afterwards died. Three others were wounded but recovered. It is not known definitely how the accident occurred. It seems probable, however, that the "go-devil" lodged in the well, and so did not reach the nitro-glycerine until after the "squib" was dropped. This released the "go-devil," which fell to the bottom and discharged the shot. The explosion blew the "squib" to the top of the well, but did not explode it. The fuse, however, continued burning, and at the end of 3 minutes discharged the "squib," with the terrible results mentioned.

About 2 miles north from Whipple 10 wells have been drilled on the Lauer, Babson and Blake farms. Of these 4 only were producers, and all were in a shallow sand. One mile northeast from Whipple 5 wells have been drilled on the Biehl farms, but little has been secured to repay the operator for his outlay. From this territory south to Marietta wells have been drilled from time to time in the valley of Duck creek, but they have been either dry, or so small that they can be recorded with the failures.

MONROE COUNTY.

This county, which lies north of Washington, is one of the largest producers of oil in the southern part of the state. It is also one of the most recent in development. The surface formations, consisting very largely of sandstones and shales, belong almost entirely to the Monongahela formation or Upper Productive Coal Measures, and to the Dunkard formation or Upper Barren Measures. The topography is very rough, especially in the southeastern part, where the hill-tops rise more than 600 above the valley of the adjacent Ohio. The oil is found principally in the southern half of the county, where, because of the infertility of the soil and ruggedness of the topography, it has proved a great boon to the residents. In this connection it must be borne in mind that the operator and owner of the land do not by any means derive all the benefits resulting from the discovery of oil. Those who own land adjacent to the producing territory option their property at a rate per month varying commonly from 10 cents to one dollar per acre. In many cases these options are carried for years, making in the aggregate a handsome sum for the farmer, without expense or trouble on his part. Besides, drilling and operating

furnish work for a large number of men and teams, and the wages are always excellent. The liveryman, grocer, butcher, gardener and, in fact, practically every man in the community is financially benefited.

The principal pools in the county are:

1. Sistersville.
2. Jackson Ridge (Griffith P. O.).
3. Graysville.
4. Moose Ridge.

Besides these the following minor pools are to be noted:

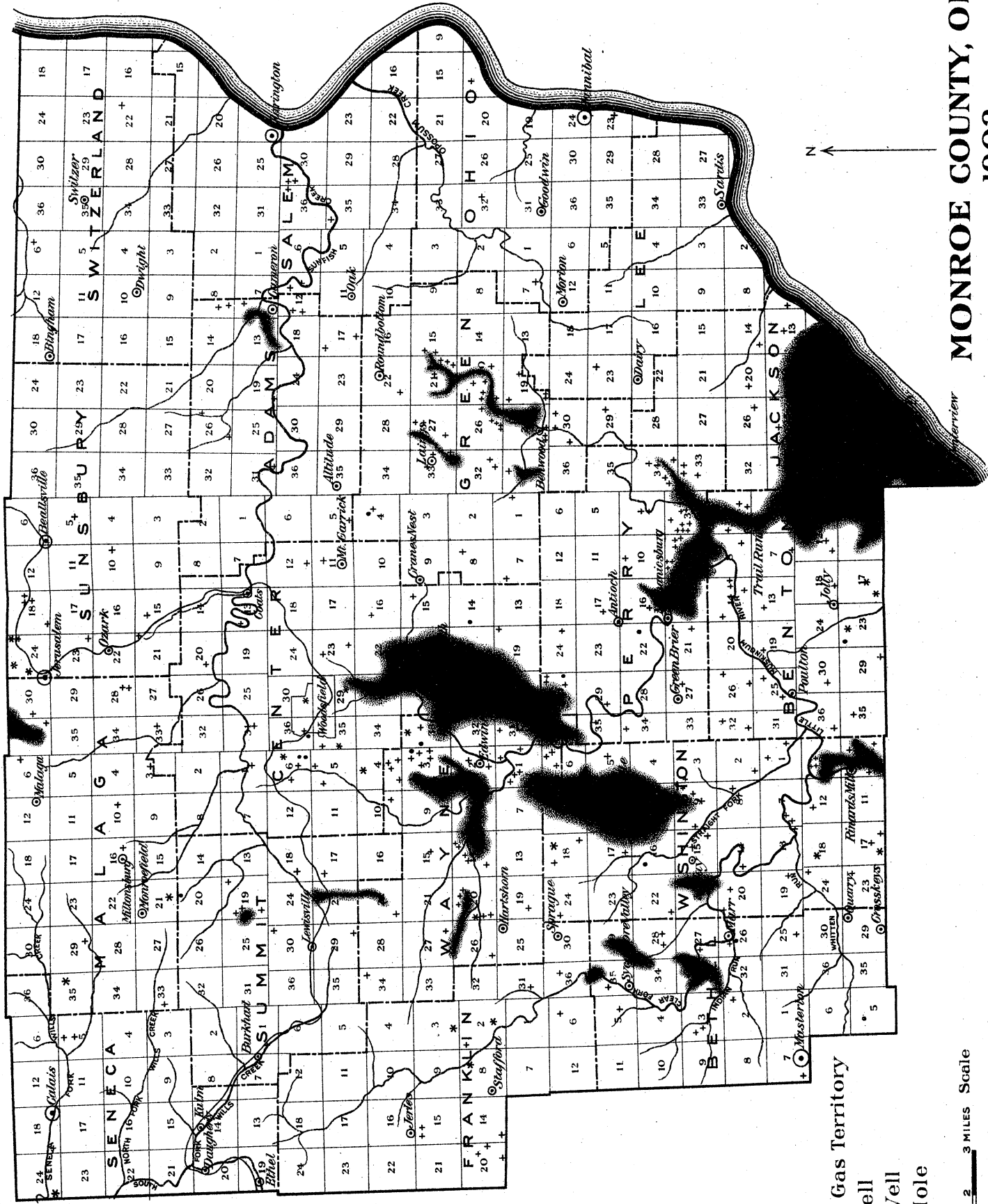
- | | |
|-------------------|----------------|
| 1. Clear Fork. | 6. New Castle. |
| 2. Clift. | 7. Louisville. |
| 3. Whitacre. | 8. Sycamore. |
| 4. Rinards Mills. | 9. Jerusalem. |
| 5. Benwood. | |

THE SISTERSVILLE POOL.

Location and Area.—This lies in the two states, Ohio and West Virginia, and is divided in two parts by the Ohio river, but that part only lying north of the river will be considered in this report. It comprises the southwestern half of Jackson township; sections 1, 2, 5, 6, 7, 8, 11 and 12 of Benton; sections 3, 9, 15, 16, 33 and 34 of Perry; and besides a strip about one mile in width along the eastern margin of Grand View township, Washington county, which joins Jackson township, Monroe county.

Discovery and Development.—In 1890 a "wild-cat" well was drilled a few miles back from Sistersville at a locality known as "Pole-Cat." A vast reservoir of salt-water was found in the Big Injun sand, and the well, which was considered valueless, was left standing idle for about 18 months. In April, 1891, a well was begun on the Ohio side of the river on the Stewart farm, opposite Sistersville, by Hatfield and Younger, of Pittsburg, for the Miller's Run Oil Company. The sand was reached May 14, and the well finally completed June 26. This was the first producer in the field, and marked the opening of one of the largest pools yet discovered in this country. When put to pumping it produced ordinarily from 10 to 15 barrels of oil per day, but with this a large amount of salt-water; sometimes when the latter was temporarily overcome the oil increased to 60 or 70 barrels per day. The productive sand is said to have been both the Keener and Big Injun, but principally the latter. Later in 1891 a well was drilled on the Russel Heirs' farm, adjoining the Stewart, and duplicated the record of the well just described. Other wells were drilled the following fall and winter on neighboring farms; oil was secured in all, but with it came a flood of brine.

MAP VI.



- Oil or Gas Territory
- Oil Well
- * Gas Well
- + Dry Hole
- Town

1 2 3 MILES Scale

In the winter of 1891-2 a well was drilled in Sistersville, which produced oil and brine in large quantities, the former from 90 to 100 barrels per day. From this well drilling extended towards the "Pole-Cat" well, and large producers were secured, but in all cases a vast amount of salt-water with the oil. Finally in 1892 it was decided to begin pumping the "Pole-Cat" well, with the hope that by reducing the salt-water, oil might be secured. The quantity of brine pumped from this well is said to have been 3,500 barrels per day for weeks. At last it began showing oil and gas; this increased steadily until a production of from 500 to 600 barrels per day was secured. This triumph of the "Pole-Cat" well gave the field a great boom, and made it for the time the Mecca of the oil men of the country. Drilling progressed as rapidly as the energy of the driller and operator combined could push the work; many large wells were secured, the greatest on the Ohio side making 1,200 to 1,500 barrels daily. After the limits of that part of the field along the river had been determined, the drill moved northward, and a number of producers were secured along Trail run, in the northeastern corner of Benton township. That part of the field, however, is narrow and unimportant, but along the line separating Benton and Perry townships it expands, forming a fine pool. This is commonly known as the "Trail Run" or "Iron Bridge" field, and was opened in 1895, the first well having been drilled on the Mathias Dye farm. Late in the spring of that year a well producing over 300 barrels per day was completed on the Freedman farm, and early in August a large gusher was struck on the J. R. Diest farm. Oil was thrown over the top of the derrick, and it is estimated that 1,000 barrels were wasted before the well could be brought under control. This started the boom, and during the following year work was pushed with great vigor. On the Diest farm of 125 acres five or six strings of tools were at work at the same time. A number of fine wells were secured, the largest being J. R. Diest No. 4, which was estimated by the Buckeye Pipe Line Company to have produced 2,400 barrels the first 24 hours. It averaged from 700 to 800 barrels per day for a month. The oil sand is the Big Injun; rarely only is a well found in the Keener. The most striking feature of this part of the field in comparison with that along the Ohio river is the great decrease in the quantity of salt-water; so great is the change that the brine, instead of being a great obstacle, is really none at all.

From the area near the "Iron Bridge" the productive territory extends northwest to Mechanicsburg (Aitch P. O.), in section 16 of Perry township. This is the part of the Sistersville field that was last developed. A well was drilled on the Daniels farm about 1896-7, but owing to legal complications it was not pumped until 1899. Active work began that year, and was at its height in 1900. The producing sand is the Keener. All in all, the wells are smaller than those in other parts of the field; the largest started at 100 barrels, and the greater number at from 10 to 40

barrels per day. Like the territory around "Iron Bridge," salt-water is not an obstacle.

Geology of the Field.—The surface formations lie in the Monongahela formation or Upper Productive Coal Measures, and the Dunkard formation or Upper Barren Measures. The underground succession is shown by the following records:

G. Carpenter well No. 1, opposite Sistersville. Authority, Henry Oil Company:

	Feet.
Top of Cow Run sand	690
Bottom of Cow Run sand	705
Top of Salt sand	905
Gas at	910
Bottom of Salt sand	1,155
Top of the "Big Lime"	1,265
Bottom of "Big Lime"	1,300
Top of the Big Injun sand	1,300
Bottom of the Big Injun sand	1,430
Top of the Berea grit	1,804
Bottom of the Berea grit	1,807
Bottom of well	1,895

Well No. 14, J. R. Diest farm, on or near section 9 of Perry township. Authority, the Associated Producers' Oil Company. Data furnished to Survey by Mr. H. M. Stanberry, C. E. Surface elevation, 909 feet:

	Feet.
Conductor	10
Sandstone	80
Shale	20
Red rock	20
Shale	20
Sandstone	30
Coal (unmeasured)	
Shale	30
Sandstone with lime	30
Shale and shells.....	160
<i>199 ft. of 10 inch casing.</i>	
Sandstone	35
Coal in the sandstone at	420
Shale and shells.....	65
Limestone	35
Red rock	75
Slate and lime	25
Red rock	40
Slate and shells	90
Sandstone and lime.....	80
<i>830 ft. of 8 inch casing.</i>	
Slate and shells	100
Sandstone	25

	Feet.
Slate and shells	45
Limestone	10
Sandstone and lime shells	90
Black shale with coal seam	25
Sandstone	40
Dark shale	20
Slate	75
Dark sandstone	45
Light slate	100
Sandstone	20
Dark slate	50
1,490 feet of 6¼ inch casing.	
"Big Lime"	60
Keener sand, show of oil.....	25
Slate	15
Big Injun sand.....	18

The great guide-post of the driller in this part of the territory is the Mountain limestone or "Big lime," as it is popularly known among the drillers. This is everywhere present in the field, and has a thickness ranging from 35 to 110 feet. It has a light color, is quite hard and hence easily recognized. The great formation appears to be here unbroken, but farther north in this county it is interbedded with layers of sands which sometimes contain valuable deposits of oil. Directly above the "Big lime" a bed of sandstone is occasionally found; this sometimes makes a show of oil, but never becomes an important producer on the Ohio side of the Sistersville field. The West Virginia geologists call this sand the Maxton.

The Oil Sands.—The oil sands of this pool lie immediately below the Mountain limestone or "Big lime," and comprise the Big Injun group. This is here divided as follows:

The	{ Keener sand.
Big Injun	{ Shale (break).
group.	{ Big Injun (proper).

The Keener sand, which lies immediately below the Mountain limestone, was named from the Keener farm, near Sistersville. On the Ohio side the sand has a thickness ordinarily of from 20 to 30 feet. It is frequently a producer of oil, but is not the principal source until the village of Mechanicsburg is reached, in the extreme northwest corner of the field. Below the Keener is a "break" or a bed of shale, having a thickness ordinarily ranging from 5 to 35 feet, and rarely disappearing altogether. Below the "break" lies the third member of the group, the Big Injun proper, having frequently a thickness of more than 100 feet. When the "break" disappears, the two oil rocks run together, forming a sandstone of great

thickness, which, of course, is known as the Big Injun. The thickness of the three formations ranges from 160 feet on the west side of the field to 250 feet on the east side.

The sand varies much in texture; sometimes it is fine and hard, at other times coarse and open. The latter is commonly true in the pay streaks, when the rock occasionally becomes a true conglomerate. In that part of the formation lying below the "break" two pays are occasionally found, the principal one lying a short distance below the cap-rock and having a thickness varying from 5 to 15 feet. The second pay lies deeper in the rock, is thinner and less important than the upper one. The size of shots used in these wells has varied greatly, having naturally been dependent on the nature of the sand. When the latter is coarse and loose, the shots have been small, in some places three quarts only; but when the sand has been found hard and fine the shots have been much heavier, reaching 100 quarts. Some wells in the field have been shot 6 or 7 times; in such cases the first shots have usually been small, and the size increased with the succeeding ones.

The wells on the Ohio side were never great producers of gas, though originally the supply was adequate for operating the territory. The gas, however, decreased more rapidly than the oil, and about 1898 suction pumps were introduced. This greatly augmented temporarily the supply, but even with this method in operation the gas has become so weak that it is scarcely adequate to meet longer the demands of the operator. The staying qualities of the sand, so far as the supply of oil is concerned, varies considerably in different parts of the field. The wells near the Ohio river have lasted better than those farther back. However, by 1898 the operators began abandoning the smaller ones, and in 1901 one company was pulling the casing from all wells that made less than one barrel per day. Another company, however, was still pumping wells that made only one-sixth of a barrel per day. The sand in the territory known as the "Iron Bridge" has given out quicker than that farther south, and although it was not developed until 1895-6, many of the wells had been abandoned by 1901. At one period in 1895 the daily production of the Diest farm was 2,500 barrels; in June, 1901, it was less than 20 barrels. Adjacent farms give similar results. The Keener sand territory around Mechanicsburg has not yet been developed long enough to determine the staying quality of that locality.

The most striking characteristic of the field is the salt-water. It is estimated that the "Pole-Cat" well alone pumped 3,500 barrels per day for weeks. The brine from the hundreds of wells made the creeks salt-water streams, while these emptying into the Ohio made that river brackish at low water. The quantity of brine diminishes to the northwest, and as has already been stated, is not a serious obstacle around the "Iron Bridge" and Mechanicsburg. The mingling of oil, gas and salt-water in the Sis-

PLATE III



VIEW OF THE FORMATION AT BLACK HAND

IN SOUTHEASTERN OHIO THIS BECOMES THE BIG INJUN, KEENER, AND
SQUAW SANDS.

tersville field is ascribed by Prof. White to the flatness of the anticline, the relief not being sufficient to permit the separation of the substances. The top of the anticline is near the village Cochranville, on the western edge of the field, and the sand there lies 60 feet higher than it does along the eastern edge of the field. The sand rises to the northwest, lying more than 100 feet higher at the "Iron Bridge" than it does opposite Sistersville, a condition that readily explains the decrease in the salt-water in that part of the territory. Since the summit of the arch lies near the western side of the pool, it follows that the producing territory lies chiefly on the eastern slope; a condition that prevails in nearly every pool in eastern Ohio in which the nature of the anticline has been determined.

Outside of the producing territory, many wells have been drilled with the hope of extending the field. The results have been as follows:

Benton Township.—Three dry holes in the southeastern quarter of section 14 on the John C. Allen farm; one dry hole in the northeast quarter of the same section on the Arch. States land, and one well making a show of oil on the Rosanna Cline land, adjoining the States. One dry hole in the northeast quarter of section 26 on the S. H. Cline farm, and one dry hole near the south line of the same section on the H. A. Williamson land. One dry hole in the northeast quarter of section 32 on the Sarah J. McHugh farm, and one in the southeast quarter of the same section on the Marshall Cline place. One dry hole on the H. A. Williamson farm in the northeast quarter of section 25, also a dry hole on a small lot near the middle of this section. A dry hole on the Cyrus McHugh farm in the northwest quarter of section 19. One dry hole in the northwest corner of section 13 on the Cyrus McHugh land. A dry hole near the south line of section 7 on the Hugh Dines farm. A dry hole on the southwest corner of section 12 on the William Busche place. One dry hole near the south line of section 18 on the T. Stacy land. A dry hole in the southwest quarter of section 30 on the J. C. Lohr farm. A dry hole in the southwest quarter of section 36 on the Sarah A. Knowlton land. A dry hole on the J. W. Lisk farm in the northwest quarter of section 35. A dry hole on the James Swallow land in the southeast quarter of section 29. A gas well on the Joseph Algeo farm in the northwest quarter of section 23. Two gas wells on the J. W. Hensel land in the southern half of section 17.

Jackson Township.—Nearly the whole of this township is occupied by producing territory, and the northern boundary is marked by a series of very small wells rather than by dry holes. On the Joseph Witten farm, near the middle of section 13, a dry hole has been drilled, also one on the William Bowen farm, on the river bank near the eastern margin of the township. One on the Thomas Hissom farm in the southeast quarter of section 26. One on the Hubbard land near the middle of section 20. One on the James Mishnack land in the southwest corner of section 14. One on the V. Voegler farm near the middle of section 33. The narrow strip

of territory extending northeast from the "Iron Bridge" is bounded on each side by a row of dry holes.

Perry Township.—A number of dry wells have been drilled along the margin of the producing territory from the "Iron Bridge" northwest to Mechanicsburg. Outside of this belt the following failures are recorded; One on the M. J. Booth farm near the middle of section 27; one on the William Foraker farm near the north line of section 34; one on the Hobbs farm near the north line of section 10; a dry hole, a small gas well and a small oil well on the J. Hubaker farm in the southeast quarter of section 4; a small oil well on the G. W. Baker farm in the northwest quarter of section 11; two dry holes in section 17, both in the southwest quarter, one on the I. C. Davidson farm, the other on the J. J. Dornbush farm; one dry hole on the S. G. Cox farm near the west line of section 29; one on the J. Drum place in the northeast quarter of section 35; one on the N. Sinclair farm near the eastern line of section 24.

JACKSON RIDGE POOL, (GRIFFITH P. O.)

Location and Area.—This lies chiefly in the southern projection of Center township, but extends southwest into section 30 of Perry and west into sections 31, 32, 33 and 36 of Wayne. On the southwest it approaches within a mile of the Graysville pool, and on the west side within less than a mile of the Moose Ridge pool. Possibly further drilling may connect all three pools, though from the dry holes already found this does not seem probable. The producing territory extends about 42 degrees east of north.

Discovery and Development.—In the spring of 1896 a well was drilled on land of Albert Johnson near Jackson Ridge by the Galey Brothers. A show of oil was found in the Keener sand and considerable gas near the bottom of the same formation. The drill was forced into the Big Injun with the hope of securing a larger production, but that sand was barren. The well was regarded with so little favor that it was not shot until the following year, when it began producing 15 barrels of oil per day. It yielded considerable gas also, which was used in further testing the field. The well is still producing (1901). In the fall of the same year (1896) a well was begun on the Hamilton farm, adjoining the Jackson. It was completed the following winter, probably in January, and began producing 5 barrels per day. The third well was begun on the Nelson Covert farm in the spring of 1897. The oil sand was struck in May, and began producing 25 barrels per day without having been shot. This well attracted oil men from other fields, and soon the Jackson Ridge territory was being extensively tested. Work has been in progress ever since, though it was comparatively quiet when visited in the summer of 1901. It seems probable that much the better part of the territory has been drilled, though work on a smaller scale will probably be done for some time. The number of producing wells in July, 1901, was about 300.

Geology of the Field.—The principal underground formations are shown by the following records, furnished by the Fisher Oil Company:

Well No. 1, George Keller farm:

	Feet.
Top of Cow Run sand	547
"Break" at	740
Bottom of Cow Run sand	940
Top of "Big lime"	1,080
Bottom of "Big lime"	1,214
Top of "break"	1,214
Bottom of "break"	1,220
Top of Keener sand	1,220
Total depth	1,258

The sand marked "Cow Run" can at the most belong in part only to that formation. The lower part occupies the place of the Salt sand, and doubtless constitutes a part of that formation. The term "Cow Run" is often applied by the driller to almost any sand lying above the "Big lime." It is very difficult, if not impossible, to identify this sand in Monroe county, since the principal formations by which it is recognized are the Cambridge and Ames limestones, neither of which is reported by the driller.

Well No. 1, M. Wool farm.

	Feet.
Top of Keener sand	1,406
Bottom of Keener sand	1,446
Top of Big Injun	1,470
Bottom of Big Injun	1,575
Top of Berea grit	1,972
Bottom of Berea grit	1,978
Total depth	2,031

The oil and gas are derived from the Keener sand, though occasionally a show of both is found in the Big Injun. The producing sand has commonly a thickness ranging from 25 to 40 feet, thinning northward and thickening to the south. Frequently the sand is pebbly; especially is this true near the top. The wells are usually shot with from 60 to 100 quarts, but charges reaching 160 quarts have been used. The results of such heavy shots, however, have not been helpful, at any rate they do not seem to have done better than lighter shots would have done. When the wells have been shot a second time, the later charge has usually been heavier than the earlier one.

The Mountain limestone or "Big lime" which lies above the Keener sand is thinner than it is to the south and southwest. According to Mr. A. L. Johnson, of the Fisher Oil Company, it has ordinarily a thickness of 80 feet, but the well records frequently show figures much smaller than this. Occasionally the limestone contains a bed of sand interstratified, and this usually contains salt-water.

Oil and Gas.—On the northwest side of the field much gas is found, the closed pressure reaching 400 pounds in some wells; but elsewhere the quantity is very small, not sufficient in some cases to develop and operate the territory. This has necessitated hauling coal from Safford, near the western edge of the county, more than 10 miles distant. The oil has a gravity of 47 deg. B., and is of excellent quality. The largest wells started at about 100 barrels daily, but the average has been much less than this; however, while the wells do not have usually a large initial production, they do have excellent "staying qualities," making the pool one of the most valuable ones in this part of the state. According to the report of the gauger for the Buckeye Pipe Line Company the 300 wells in the field were making 55,000 barrels per month during the summer of 1901. Salt-water is not abundant, but increases southward, where it adds to the expense of operating the territory. The wells are cased usually to the top of the "Big lime."

Other Wells in Center Township.—Many wells have been drilled in this township with the hope of finding a northward extension of the Jackson Ridge and Moose Ridge pools, but thus far the results have been almost entirely negative. The locations of these wells are as follows: A well making a show of oil on the Ferrenbach land in the northeast quarter of section 12; a gas well on the Short farm near the north line of section 4; a dry hole on the Brubach farm in the northwest quarter of section 5, and one on the Brothers' estate in the northwest quarter of the same section; four wells in section 6, a dry hole near the middle of the section on the Brubach land, a small oil well on the Cooke farm in the southeast quarter; a gas well on the Kerr land in the northeast quarter and a dry hole on the Ferrenbach farm in the northwest quarter; a dry hole on the McCannon farm in the southeast quarter of section 1; a small gas well (now abandoned) on the Holida land in the southwest quarter of section 35; two wells near the south line of section 36 along the B. Z. & C. R. R., one yielding gas and the other some oil; a dry hole on the Clingan farm in the northwest quarter of section 31; two dry holes on the Shumacher farm near the middle of section 23; a dry hole on the Burkhead farm in the southwest quarter of section 20; a dry hole on the Stout farm near the middle of section 16; two dry holes in section 13, one on the Shumacher farm near the east line and one on the Windland farm in the northwest quarter; a dry hole on the Clanges farm in the southeast quarter of section 10; a dry hole on the Mooney farm in the southeast quarter of section 12.

THE GRAYSVILLE POOL.

Location and Area.—This lies almost entirely in Washington township, embracing sections 4, 5, 6, 10, 11, 12, 16 and 17. Beyond this township the pool extends northward into Wayne, where it includes parts of

sections 1 and 7. The productive belt runs 40 degrees east of north, has a length of four miles and a maximum width of two miles.

Discovery and Development.—In the winter of 1895-6 a well was drilled on the Delaplaine farm in section 11, near the village of Graysville. It made a good showing of oil in the Keener sand, but not sufficient, in the judgment of the drillers, to warrant shooting, and so the well was abandoned. However, the test was not regarded as conclusive, and accordingly a second well was soon begun, but this made a poorer showing than the first one, and so was abandoned without having been shot. A third well was completed on the same farm in December, 1897, with results entirely similar to the preceding two. These failures discouraged further exploration, and nothing more was done until 1900, when the Devonian Oil Company drilled a well on the same farm and about 75 yards from the first well. This well was completed in June, and after having been shot with 100 quarts of nitro-glycerine began flowing oil, producing at first nearly 100 barrels per day. The producing sand was the Keener. About one month later a well was drilled on the Eaton farm, adjoining the Delaplaine on the north. This was a success, though not so good as the one previously drilled. These two wells attracted the attention of operators in other fields, and soon the territory was being rapidly developed. The boom lasted during the summer and fall of 1900, but since then comparatively little work has been done. This has resulted partly from the decrease in price of oil, but more largely from the diminution in the size of the wells as the drill moved farther and farther from the center of the productive territory.

Geology of the Fields.—The following skeleton sections show the principal underground formations:

Well No. 1, W. A. Oden farm. Authority, Fisher Oil Company:

	Feet.
Top of Keener sand	1,333
Bottom of Keener sand	1,358
Top of Big Injun	1,380
Bottom of Big Injun	1,540
Top of Berea	1,885
Total depth	1,917

Well No. 1, J. W. Foraker farm. Authority, Fisher Oil Company:

	Feet.
Top of Keener sand	1,439
Top of Big Injun sand	1,485
Top of Berea sand	2,004
Bottom of Berea sand	2,012
Total depth	2,025

The Keener is the producing sand, except in those wells in section 9 and the southern half of section 10 which are reported in the Big Injun

proper. Two small Berea wells are found on the Mann farm in the southern half of section 5.

The Maxton sand, which lies just above the "Big lime," has a thickness commonly ranging from 15 to 30 feet. This is divided into two parts by a bed of slate. Neither of these produce oil or gas in commercial quantities, but when either is reported it is from the upper bed. The "Big lime" or Mountain limestone is from 60 to 100 feet thick, is free from beds of sand and void of oil or gas. The Keener sand does not lie immediately below the "Big lime," but is separated from it by a "break" or bed of slate, having commonly a thickness of 15 feet. The sand rock under consideration varies considerably in thickness, ranging ordinarily from 15 to 60 feet, with the average of these two figures representing the common thickness. The sand is reported pebbly at the top, but the lower part, including the pay, is finer. This character of the producing rock is doubtless responsible for the poor showing of the wells before they are shot, and was the cause of 5 years' delay in opening the field. In view of developments in 1900 it seems certain that had the early wells drilled on the Delaplaine farm been shot they would not have been recorded as failures. The Big Injun sand proper, which lies about 20 feet below the Keener, from which it is separated by a bed of slate, has ordinarily a thickness approximating 125 feet, but there are marked variations from this figure. Lying from 6 to 10 feet below the Big Injun is another sand, known as the Squaw, a name applied to a producing sand in West Virginia by the drillers of that state. A generalized section of these formations in the Graysville field is as follows:

Maxton sand	15 to 30 feet
Mountain limestone ("Big Lime")	60 to 100 feet
Slate ("break")	10 to 20 feet
Keener sand	15 to 60 feet
Slate ("break")	5 to 25 feet
Big Injun proper	100 to 150 feet
Slate ("break")	6 to 10 feet
Squaw sand	8 to 30 feet

As shown by the records previously given, the interval between the top of the Keener sand and Berea grit is about 550 feet. Well No. 16 on the Delaplaine farm is said to have reached a depth of 2,367 feet, the objective point being the Gordon sand, but the search was a failure.

Oil and Gas.—The field, like the neighboring one of Jackson Ridge, produces little gas. The supply, in fact, has been so small that it was not adequate for exploring the territory, and accordingly the driller has been compelled to rely on coal or on gas derived from another field. The wells are not heavy producers of oil, the largest having started at approximately 100 barrels per day. The field has not yet been operated sufficiently long

to determine the "staying qualities" of the sand, but its proximity to Jackson Ridge leads to the hope that the production will be long-lived. In July, 1901, there were 220 producing wells in the field, and these averaged 10 barrels each per day. Along the margin of the pool the production gradually decreases until it becomes so small that the operator will drill no further. Inside of this border the sand is rarely barren of oil, a condition adding much to the value of the territory.

The field is quite free from salt-water, little being found outside of the Salt sand, and the quantity there is not large. The wells are usually cased in the Maxton.

The landholder has usually received a royalty of one-eighth of the oil, but sometimes this has been larger, amounting in a few instances to one-fourth.

THE MOOSE RIDGE POOL.

Location and Area.—This lies west of Jackson Ridge and north of Graysville. It includes sections 2, 3, 8, 9, 14, 20, 26 and 27 of Wayne township. The shape of the pool is that of a right angle, the principal part running north and south, from the latter end of which an arm extends westward, this portion being commonly known as the Rich Fork pool.

Discovery and Development.—The pool was discovered in the fall of 1898 or spring of 1899, the first well having been drilled on the Cronin farm, in the western arm of the field. The well is reported to have started at 125 barrels per day, the producing sand being the Maxton. This well was followed by others with varying results, the sand being found spotted, so that a map of the field shows an admixture of oil and gas wells with dry holes. From this character it is readily understood that the territory is not as valuable as that of Jackson Ridge or Graysville. The dry holes already drilled outside of the pool show that the limits of the latter have now been pretty definitely determined.

That part of the pool running north and south was opened early in 1900, the first well having been drilled on the Bishop land. It is reported to have started producing 25 barrels per day, the oil being derived from the Keener sand. From this farm the drill moved in all directions, work being very active during the summer and fall of 1900. The limits of the field were determined in a few months, however, and since then drilling has been comparatively quiet.

Geology of the Field.—There are three producing sands, a shallow one known as Cow Run, the Maxton and the Keener. The relative positions of these are shown by the following records:

J. Dearth farm, well No. 1. Authority, Fisher Oil Company:

	Feet.
Cow Run sand at	715
Salt sand at.....	760
Bottom of Salt sand at.....	840
Top of Maxton sand	955

	Feet.
Bottom of Maxton sand	1,060
Top of "Big lime"	1,090
Top of Keener sand	1,150
Gas at	1,155
Oil at	1,160
Top of Big Injun	1,198
Total depth	1,224

The sand named "Cow Run" is not an important producer. Wells in it have been secured on the Willison, Daugherty and Turney farms, one having started at 25 barrels per day. The sand, however, cannot be the equivalent of the one having the same name found in Washington and Morgan counties. At Joy, in the latter county, the interval between the Cow Run and Salt sands is 470 feet, while in the above section it is 45 feet only. The sand in question might be the Second Cow Run, but it cannot be identified with certainty owing to the absence of any well-marked datum plane, such as a bed of limestone or seam of coal. With the driller the Cow Run sand is almost any one lying above the Salt sand.

The Maxton, which is the oil sand in the western arm of the field, has a thickness ranging from 8 to 100 feet. It is moderately fine, and is shot with from 30 to 80 quarts of nitro-glycerine. The formation is separated from the underlying Mountain limestone by a foot or more of slate. This limestone has a thickness which ordinarily ranges from 60 to 80 feet, is sometimes very hard and at other times soft. The Keener, which is the principal producing sand in that part of the field running north and south, has a thickness ranging usually from 28 to 35 feet. Its structure is similar to that of Graysville and Jackson Ridge. It is separated from the "Big lime" by from 6 to 10 feet of slate. Neither oil nor gas has been found in paying quantities in the Big Injun, and no records of its depth were secured.

Oil and Gas.—In that part of the field running north and south there is a well-defined oil and gas belt, the latter lying west of the former, a condition which doubtless results from the oil sand rising westward. The closed pressure in the gas wells was at first 150 pounds, but one year later had dropped to 60 pounds. The gas has been used for drilling and pumping in this field and Jackson Ridge. The largest oil well started at from 140 to 150 barrels in 24 hours, but the average has been, of course, much less than this. In July, 1901, the average daily production was 9 barrels per well. The oil has a gravity of 46 deg. B.

The oil wells in the western arm of the pool are comparable in size to those just mentioned, and the oil has the same gravity. The wells produce considerable gas, with but little salt-water. The distinctly gas wells in this arm of the field are reported in the bottom of the Keener or top of the Big Injun proper. At first these had a closed pressure of 250 pounds per square inch, but this had dropped to 110 pounds in July, 1901. The gas

wells are not restricted to one side of the field, but are intermingled with the oil wells.

THE WHITACRE POOL.

Location and Area.—This contained in 1901 less than 25 wells, lying almost entirely in section 21 of Washington township. The principal farms were the Whitacre, Hendershot and Martin. The pool lies two miles west of the south end of the Graysville field.

Discovery and Development.—The pool was opened in 1899 with a well on the Whitacre farm. No oil of consequence was secured until the Squaw sand was reached, when there was a fine yield of oil, the well flowing for several days. A well on the Knowlton farm was drilled to the Big Injun sand in the fall of 1899, but this rock being dry, the hole was extended to the Berea in the following spring. This sand was found to have a thickness of 22 feet, and after having been shot with about 20 quarts of nitro-glycerine began producing 6 barrels of oil per day, but this had decreased to 2 barrels in July, 1901. The limits of the producing territory have not yet been determined, but it does not seem probable that the pool will be a large one.

Geology of the Field.—With the exception of the Knowlton well, the producing sand is the Squaw. This lies from 8 to 10 feet below the Big Injun, and has a thickness ranging from 8 to 20 feet. It is usually pebbly, but sometimes becomes fine. The Big Injun ranges ordinarily from 120 to 140 feet in thickness, and one well recorded 170 feet. The wells are small, the largest starting at 30 barrels. The wells now (1901) average 10 barrels each per day. But little gas is produced, necessitating a dependence on coal or gas wells elsewhere for fuel.

In the southern half of Washington township, lying south of the Whitacre and Graysville pools, a number of wells have been drilled, the record of which is as follows: A dry hole on the Jacob Coss farm in the southwest corner of section 2; a dry hole on the S. A. Baker farm in the northeast quarter of section 8; a dry hole on the W. T. Springer farm in the northwest quarter of section 14; a dry hole in the northeast quarter of section 20 on the Winfield Poulton farm; two dry holes in section 1, one in the northeast quarter on the Henry Cline farm, the other in the southeast quarter on the Charles Hill place; two dry holes on the Fred Ullman farm in the southwest quarter of section 7; a dry hole on the land of George Blair in the southeast quarter of section 13; a dry hole in the southeast quarter of section 19 on the farm of Elisha Smith; four dry holes, two small oil and one gas wells near the center of section 6; one dry hole on the land of Martin Cline in the northeast quarter of section 12; a small gas well in the northwest quarter of section 18 on the land of G. W. English; three small gas wells along the southern margin of section 17, near the Washington county line; a dry hole in the northeast quarter of section 23 on the B. W. Piatt farm.

BETHEL TOWNSHIP.

There are two small pools in this township :

1. The Clift;
2. The Sycamore.

The Clift Pool.—This pool was discovered early in 1900, the pioneer well having been drilled on the Clift farm. This well is reported to have started producing 85 barrels from a sand lying in the "Big lime." The latter is not the homogenous formation in this field that it is farther east and south, but, according to reports of drillers, is divided near the middle by a heavy stratum of sand, and it is this which yielded the oil of the well referred to, and that of other wells in the vicinity. However, there are several wells in the Big Injun and occasionally a little oil is derived from the Keener. The number of producing wells in the pool is less than 20. The general succession of formations is as follows:

G. W. Martin farm, well No. 1:

	Feet.
Cow Run sand at	600
"Big lime" at	1,033
Sand in "Big lime" at	1,066
Bottom of latter at	1,100
Top of Big Injun at	1,185
Berea sand at	1,810

The Sycamore Pool.—The Sycamore pool, as developed in August, 1902, formed a narrow strip about two miles long. The number of wells completed was about 20, but ten strings of tools were at work and the number of wells is now doubtless larger.

According to William Longfellow, an experienced driller, the oil is obtained from the Keener sand. The "Big lime" ranges in thickness from 60 to 80 feet. Some salt-water is found in the Maxton sand, but very little in the Keener. The casing extends to the "Big lime."

Other Wells in the Township.—In the northern half of section 35 two gas wells have been drilled on the Wineland farm, one dry hole and one small oil well on the Bode farm, and an oil well on the lot just south of the Wineland place; a dry hole on the Lindmoor farm in the southeast quarter of section 5, and a show of oil in a well on the Bode farm in the northeast quarter of the same section; a small oil well on the Anderson farm in the northwest quarter of section 28, and a dry hole near the center of the same section on the C. D. Hartshorn place; a dry hole on the Unger farm in the northwest quarter of section 3, and one on the W. M. Martin farm in the southwest quarter of the same section; a small well on the Smithberger farm in the northwest quarter of section 26; a dry hole on the Park's farm in the northeast quarter of section 2; a dry hole on the Simmons farm in the southeast

quarter of section 25; a dry hole on the Stewart farm near the west line of section 7.

MINOR POOLS IN OTHER TOWNSHIPS.

Franklin Township.—In the extreme southeast corner of this township a half-dozen oil wells have been secured on the Wineland and adjacent farms, the producing sand being in some cases the Big Injun and in others the Keener. The first well was drilled in the fall of 1899, and began producing 5 barrels. One well has been drilled which had an initial production of 50 barrels per day. The sands produced considerable gas. Other deep wells in the township are as follows: One dry hole on the C. Hines farm in the northeast quarter of section 6; a dry hole on the T. Hines farm in the southwest quarter of section 3; a show of oil on the Wilson farm near the north line of section 1; a dry hole on the Okey farm in the northwest quarter of section 2, and a gas well in the southwest quarter of the same section; a gas well on the Carpenter farm in the northeast quarter of section 8; a dry hole on the King farm in the southwest quarter of section 14; two dry holes on the Renner farm near the east line of section 20, and one dry hole in the southeast quarter of the same section.

Green Township.—Two pools of oil have been found in this township, the Newcastle and the Benwood. The Newcastle pool extends slightly east of north and includes parts of sections 31, 32, 33, 27 and 28. Oil was discovered in 1890, the first well having been drilled on the Stevens farm. The production from this well was not large, and owing to poor shipping facilities was soon abandoned. The next well was on the Neff farm, adjoining the Stevens, and was a dry hole. Not until 1894 did work begin in earnest. In that year the greater number of wells were drilled and the limits of the pool pretty definitely determined. The Berea is the producing sand. It has a thickness ordinarily ranging from 10 to 16 feet, but sometimes disappears entirely. From this it follows that the territory is spotted, the producing wells and dry holes intermingling. On the west side of the field considerable gas is found, which is used, not only to operate this field but the Benwood as well. The oil is black and has a gravity of 41 deg. B., commanding 25 cents less per barrel than that of the other pools in the county.

The Benwood pool lies about one and one-half miles east of the Newcastle, with which it runs parallel. It occupies parts of sections 25, 26, 20, 21 and 15. At its greatest development the pool has a width of two-thirds of a mile, but usually the width is much less than this. The field was opened in the fall of 1894, the first well having been drilled on the Holtsclaw farm. This well produced little oil, but made considerable gas. The following summer a well was drilled on the Price farm, adjoining the Holtsclaw. This produced 150 barrels of oil the first day, and of course at once started great excitement. The largest well in the field is Neff No. 2, which started at 1,400 barrels. Other fine wells have been

secured, but the production has declined rapidly, the sand, which is the Big Injun, not possessing good "staying qualities." In July, 1901, by far the greater number of wells had been abandoned. In the northern part of the field many dry holes have been drilled, and this fact, coupled with the short life of the wells, has made the field an expensive one to the operators. The underground succession is shown by the following record of Holtsclaw well No. 3:

	Feet.
Coal at	410
Thickness	6
Cow Run sand.....	950
Thickness	35
Salt sand at.....	1,250
Thickness	125
"Big lime" at.....	1,470
Thickness	40
"Break" (slate) at.....	1,540
Thickness	16
Big Injun sand.....	1,556
Thickness	71
First "pay" at.....	1,570
Second "pay" at.....	1,595

Adams Township.—The first deep well in this township was drilled in 1887 or 1888 on the land of George Suppes, near the village of Cameron. A flow of oil is reported to have been struck in the Big Injun sand, but the oil was accompanied by a heavy flow of salt-water, which discouraged the operators so far as the Big Injun sand was concerned, and accordingly they determined to drill on to the Berea. This was found at a depth approximating 2,000 feet, but was dry. The well stood idle during four or five years and then was pumped for a short time, and finally abandoned. No further testing seems to have been done until 1896, when another well was drilled on the same farm. A 15-barrel producer was secured in the Big Injun sand, but later when the well was shot a second time a large flow of salt-water was liberated, and this ruined the well. During the years 1896-7 work in the field was quite active, the testing being done principally in sections 13, 14, 18 and the half-section lying east of 13 and 18. Several good wells were secured; one on the Mobley farm in the north-east quarter of section 13, drilled in 1897, started at 160 barrels per day, and is still producing; another large well was Greathouse No. 2, lying east of the Mobley, and starting at 130 barrels. The sand, however, was soon found to be very spotted, and the production of oil short-lived. As late as 1902 a well was drilled occasionally, but it does not seem probable that much work remains to be done in this locality. All the producing wells are in the Big Injun sand, the oil being derived near the top, while further down brine is encountered. The Maxton and Keener sands are recognized, and each occasionally makes a show of oil.

Outside of the Cameron field a number of wells have been drilled in this township; a dry hole on the Bracy farm in the southeast quarter of section 31; a dry hole on the Vanert farm in the southeast quarter of section 26; a dry hole on the Pfalzgraff farm in the southwest quarter of section 19; a dry hole on the John Winkler farm in the northeast quarter of section 17.

Salem Township—A number of deep wells have been drilled in this township, but thus far neither oil nor gas has been found in marketable quantities. The locations of the wells are as follows: One on the Henthorn farm in the southeast quarter of section 7; two in the eastern half of section 12, one on the Boughner and the other on the Maurray farm; one on the Ward land in the southwest quarter of section 8; one on the Arn land in the northwest quarter of section 35; one on the Yost farm in the northwest quarter of section 30. It is probable that all these wells reached the Big Injun sand.

Summit Township.—Drilling in this township has been largely confined to two localities, (1) on the Ludwig and Matz farms in sections 19 and 25, and (2) on the Wise and adjacent farms about one mile east of Lewisville.

A well on the Matz farm in section 25 was completed December 26, 1900, and started at 8 barrels; in July following the production was 5 barrels per day. Early in the spring of 1901 a well was drilled on the Ludwig farm, which adjoins the Matz on the east. The production was at first about 75 barrels per day, and was 25 barrels in July of the same year. The oil is reported to have been derived from a sand in the "Big lime." Besides the 2 producing wells in this locality on July 1, 1901, 4 wells had been located, and three dry holes drilled, one on the Friday farm in the northeast quarter of section 30, and two in the southwest quarter of section 19 on the Konig and Black farms.

The territory east of Lewisville was opened in 1899, the first well having been drilled on the Wise farm. This began producing 10 barrels per day, but soon dropped to 2 or 3 barrels and was abandoned in the summer of 1900. The same year a well was drilled on the Diehl farm, adjoining the Wise, but was dry. The first good well in the field was drilled in the spring of 1901 on the Wise farm, and is reported to have begun producing from 75 to 100 barrels per day from a sand in the "Big lime." About the same time another well was drilled on the same farm by Galey Brothers & Mooney, which started at 100 barrels per day. On July 3, 1901, a well was completed on the Sperry farm which started at 300 barrels per day, and produced over 9,000 barrels of oil the first month, and 60,000 the first year. This well has been a remarkable producer. It was reported to be yielding 60 barrels per day in August, 1902. Several wells were later drilled on the same farm, and all were small producers, starting at from 25 to 75 barrels per day. Just before the large well above referred

to was completed the drillers, Galey Brothers & Mooney, sold a half interest in it to Roy Brothers for \$1,600, about the cost of the well. The oil is reported from a sandstone lying beneath from 10 to 15 feet of lime-rock, which is presumably the "Big lime." On this basis the sandstone is the Keener. The small thickness of the "Big lime" is in harmony with what has been stated elsewhere, viz; it thins rapidly to the west and is soon replaced by sandstones and shales.

The general succession of strata is shown by the following record:

F. C. Neuhart well No. 1, located about two miles northeast of Lewisville. J. M. Guffey & Co., owners. Data furnished by George Troutman:

	Thickness of stratum. Feet.	Total depth. Feet.
Conductor	12	12
Slate	20	32
Sand, white	40	72
Slate	27	99
(88ft. 10 in. casing.)		
Lime	12	111
Slate	14	125
Lime	7	132
Red rock	13	145
Slate	27	172
Lime	20	192
Slate	43	235
Sand	10	245
Coal	2	247
Slate	12	259
Lime	22	281
Slate and sandy shale.....	46	327
Slate and lime.....	30	357
Sandy shale	43	400
Red rock (called "Big red").....	100	500
Sandy shale	21	521
(500 ft. 8in. casing.)		
Red rock	40	561
Slate	50	611
Red rock	15	626
Slate, white	21	647
Slate, black	53	700
Sand, First Cow Run.....	45	745
Slate—gas at 755 ft.....	10	755
Sand, Second Cow Run.....	60	815
Slate	5	820
Sand (Salt Sand).....	105	925
Coal	4	929
Slate, white	29	958
Sand, gray	103	1,061
Slate, black	20	1,081
Sand, white	15	1,096
Sand, black	20	1,116
Slate, black	9	1,125

	Thickness of stratum. Feet.	Total depth. Feet.
(1,125 ft. 6¼ in. casing.)		
Slate, black	40	1,165
Sand, gray	33	1,198
Slate, black	3	1,201
Sand, white	29	1,230
Sand, black	29	1,259
Sand, white	20	1,279
Lime (called "Big lime")	36	1,315
Slate	30	1,345
Sand, Keener	42	1,387
Slate	3	1,390
Sand, Big Injun.	170	1,560
Slate	20	1,580
Slate and shells	275	1,855
Sand, gray	10	1,865
Slate, black	57	1,922
Sand, Berea	4	1,926
Slate	30	1,956

Outside of the two localities already described a few wells have been drilled in the township; a dry hole on the Buchanan farm in the southwest quarter of section 18; a dry hole on the Young farm in the northwest quarter of section 13; two wells in the southeast quarter of section 29, a dry hole on the Denbow farm and one making a little oil on the Webb farm.

Malaga Township.—In the winter of 1901-2 a small pool was opened in section 36, less than two miles west of Jerusalem. The first well, which was drilled on the Harper farm, is reported as having begun producing oil at the rate of 300 barrels per day. By August, 1902, nearly a dozen oil wells had been completed, and a few gas wells. The pool extends into Belmont county, though at the time the territory was visited only one oil well had been secured north of Malaga township.

The "Big lime" in this field is reported 40 feet thick. About 20 feet below it the Keener is found, and this contains the oil. The upper part of this formation is reported pebbly, and the lower portion a sandstone. Oil is found in the upper part and salt-water below. The limits of the field have not yet been determined.

Outside of this pool a number of wells have been drilled; two dry holes in the northwestern part of section 30; one dry hole in the northeast corner of section 35; two dry holes in the southern part of section 28; one dry hole in the southern part of section 33; one dry hole in the southeastern part of section 4; one small gas well in the southeast quarter of section 3; one dry hole in the southeast corner of section 6, and two oil wells in the southwest quarter of the same section; one dry hole in the southeast corner of section 10; one gas well in the southeast quarter of section 16; one gas well in the southeast corner of section 21; one gas well in the northeast

quarter of section 35; and one dry hole in the southeast quarter of section 29.

Scattering Wells in Other Townships.—In Seneca township two deep wells have been drilled, a dry hole near the middle of section 5, and a gas well in the southwest corner of section 24. In Sunbury township more than a dozen deep wells have been drilled in the western half of the township. They are located in sections 5, 10, 15, 16, 18, 21, 23 and 24. All are dry holes except three in section 24, which make some gas. In Ohio township several deep wells have been drilled, a dry hole and a well making a show of oil on the Muhlman farm near the north line of section 14, a dry hole on the Kesserman farm in the northeast quarter of section 32, a well making a showing of oil on the Winkler farm in the southeast quarter of section 7, a dry hole on the Fisher farm near the south line of section 30, and a dry hole in the valley of the Ohio on the Bridgman farm in section 23. In Lee township a dry hole has been drilled in the northeast corner of section 23, and a well producing gas on the Goddard land in the southeast corner of section 11.

BELMONT COUNTY.

A large amount of drilling for oil and gas has been done in this county, but the results have not been commensurate with the labor and money expended. No large area in the county remains untested, and hence it is unreasonable to expect that extensive tracts of producing territory will be discovered, though small but valuable pools or reservoirs may yet be found. The surface rocks belong largely to the Monongahela formation or Upper Productive Coal Measures. Of the pools already found the following deserve special mention:

1. Barnesville;
2. Temperanceville;
3. Colerain.

THE BARNESVILLE OIL AND GAS FIELD.

This lies immediately west of the city limits, and extends northeast and southwest. It has a length of two miles and a maximum width of one mile.

The first deep well in the vicinity of Barnesville is reported to have been drilled early in 1887, the expense having been met by the city which, under authority from the Legislature, had bonded itself for \$5,000. The search appears to have been begun for gas rather than for oil, which was desired for the glass factory and for domestic purposes. The well, as reported by Dr. Orton, had a depth of 2,700 feet, the Berea having been struck at about 1,600. The Berea made a little oil and considerable salt-water, and so must be assigned to the long list of failures. This, however, did not discourage the citizens, and on March 25, 1887, the Warren

Oil and Gas Company was incorporated with a capital stock of \$5,000, divided into shares of \$100 each. On May 1, 1889, this was increased to \$25,000, and on January 16, 1894, the company voted to increase the stock to \$100,000 for the further development of the territory. This company located its first well southwest of town on land of William Barlow, February 20, 1888. The Berea sand was found but made a show only of oil, and the second well produced similar results. Before making further exploration the company employed Mr. F. W. Minshall, of Marietta, to examine the field. He reported a low arch northwest of town, and in 1889 a well was located by him on the Parker farm on this arch. The result was a gas well having a closed pressure of 640 pounds, and a daily production of 750,000 cubic feet. Another well was soon drilled on the same property with results similar to the first one. In 1890 Dr. Orton measured these wells and reported that they produced conjointly 800,000 cubic feet per day. The gas was piped to Barnesville the same year. In 1891 two wells were drilled on the Laughlin farm, adjoining the Parker, and both were fair gas wells.

From what has just been said it is apparent that during the early years the territory produced gas only. Early in the winter of 1893 a well drilled on the Parker farm east of the gas wells began producing 25 barrels of oil per day, thus proving the existence of oil as well as gas in commercial quantities. Drilling has been in progress in the field from time to time since that date. In August, 1901, the daily production was reported by the guager to be 175 barrels per day. In December, 1902, the 25 oil wells of the field were producing from 30 to 35 barrels in the same period. The gravity of the oil was reported by the guager to be 46½ degrees B. As soon as oil was discovered the Buckeye Pipe Line Company entered the field and began shipping the product in tank cars, but in 1895 it laid a pipe line to Sistersville, West Virginia.

In 1898 the Warren Oil and Gas Company sold its gas wells to Treat and Crawford, and in 1899 its oil wells. Gas is furnished to about 500 customers and to two glass houses (July, 1901), but the local supply is increased from the Dudley field, in Noble county. The price of gas was at first 10 cents per thousand cubic feet; in 1897 it was doubled, but opportunity is afforded to reduce this 5 per cent. by paying the bills before the 10th of the month.

The following figures show the daily production in cubic feet of the oldest gas wells at different periods during the first five years of their history:

	1889 (when first drilled).	April 26, 1892.	April 20, 1894.	April 26, 1895.
Parker No. 1.....	750,000	66,703	.....	.....
Parker No. 2.....	750,000	174,364	99,960	71,665
Laughlin No. 1....	.....	266,804	142,800	100,378
Laughlin No. 2....	.....	159,966	95,166	50,000

The oil and gas are derived entirely from the Berea grit, which is found in almost every well, and in normal conditions. The gas pressure is generally sufficient to flow the wells, and this has diminished the cost of operating them. As has already been stated the producing territory forms a low anticline.

THE TEMPERANCEVILLE FIELD.

This lies in Somerset township, Belmont county, and Beaver township, Noble county. It lies due north of Temperanceville, and extends north and south. As developed in July, 1901, the length of the field was two miles and the width one mile.

The pool was discovered in December, 1899, the first well having been drilled on the Pfeffer farm. This began producing 17 barrels per day, and in July, 1901, was producing 10 barrels daily, indicating that the production will be long maintained. From that time drilling has been done, though not with great rapidity, owing in part to the producing territory belonging to one company. Twenty-seven wells were drilled in the pool by July 15, 1901, and of these only two were dry, but the two at the south end of the field were so small that they were almost valueless. Only one gas well had been drilled when the field was visited, and that lay on the extreme west side. The best oil well in the pool started at 35 barrels per day. The few dry holes found justify the hope that the producing territory may be considerably extended. The Berea grit is the producing rock. The production of the pool in July, 1901, was 175 barrels per day. Like the Barnesville field nearly all of the wells flow. The gravity of the oil was reported by the gauger for the Buckeye Pipe Line at 40½ degrees B. The oil is pumped to Sistersville. In November, 1902, there were 28 wells in this field, the daily production being 110 barrels.

The following record of Pfeffer well No. 1 shows the general underground succession. The head of the well is reported to be at the level of the Pittsburg coal. Data furnished by S. B. Hughes, representative of the J. M. Guffey Company:

	Feet.	Feet.
Soil	5	5
Lime, blue, hard.....	50	55
Slate, red, soft.....	105	160
Slate, white, soft.....	20	180
Slate, red, soft.....	210	390
Slate, black, soft.....	30	420
Lime, gray, hard.....	10	430
Sand, white, soft.....	50	480
Slate, black, soft.....	10	490
Sand, gray, soft.....	8	498
Lime, white, medium.....	42	540
Sand, white, soft.....	80	620
Slate, black, soft.....	73	693
Sand, white, soft.....	44	737
Slate, black, soft.....	68	805

	Feet.	Feet.
<i>Salt sand, white, soft and hard</i>	166	971
Slate, white, soft.....	3	974
Lime, white, medium.....	24	998
Slate, white, soft.....	20	1,018
<i>Big Injun sand</i>	232	1,250
Slate, black, soft.....	3	1,253
Sand, gray, hard.....	43	1,296
Slate, blue, soft.....	6	1,302
Lime, brown, hard.....	8	1,310
Slate and shells, blue, soft and hard....	80	1,390
Slate, blue, soft.....	75	1,465
Lime, gray, hard.....	15	1,480
Slate, black, soft.....	44	1,524
Lime, black, hard.....	9	1,533
Slate, black, soft.....	12	1,545
Lime, gray, hard.....	25	1,570
Slate, black, soft.....	52	1,622
<i>Berea sand, white</i>	9	1,631

The following is a skeleton record of a well drilled on the Legler farm near Temperanceville in the early summer of 1901. Data furnished by the Sun Oil Company:

	Depth. Feet.	Thickness. Feet.
Top of Salt sand at.....	840	40
Top of Keener sand at.....	1,000	30
Top of Big Injun sand at.....	1,060	215
Top of Berea grit at.....	1,600	12
Shales		588
Total depth of well.....	2,200	

It was hoped that by drilling below the Berea grit one of the deeper sands found in a neighboring state might be struck, but the effort, like all others in Ohio having that object in view, was a failure.

The Pittsburg coal in this vicinity has a thickness of 4 feet. Drillers report a six-foot seam about 400 feet lower. This is probably the Upper Freeport coal. No well record was available, however, showing the relative positions of the two seams, and the figure just given may not be even approximately correct.

THE COLERAIN OIL FIELD.

This lies in and adjacent to the village of Colerain in the township of the same name, situated in the northeast corner of Belmont county. The productive territory is less than one mile in length, and about one-fourth of that in width. It includes a small part of sections 7, 8, 13 and 14.

The first well was drilled in 1894 on land of John Starbuck in section 7. The Berea sand is reported to have been struck at 1,872 feet. The well began producing 30 barrels of oil per day, and was not abandoned until 1899. It produced much gas and flowed for some time. The second well was drilled on the Sharkey farm, and had an initial production of 125

barrels per day. It was shot with 60 quarts of nitro-glycerine, and was not abandoned until 1900. The best well in the field was drilled on the Brackin farm, and is reported to have flowed 1,000 barrels of oil the first 48 hours, and to have averaged 300 barrels during the first 90 days. In July, 1901, the well was producing 10 barrels per day. In 1895-6 several dry holes were drilled, the result of which was to check exploration. It was soon found that the productive territory was very small, and further that the wells were short lived. Of the 30 wells drilled 18 were productive, but 3 only of these were producing in July, 1901. The heavy gas pressure gave the wells a geyser like character which did much to make the field notorious. The collapse of the boom was almost as sudden as its rise. The operators in the field were:

Thompson & Gasmire,
The West Virginia Gas Co. & T. N. Barnsdale.
The Ohio Oil Company,
The Barton Oil Company,
C. D. Hogg & Company.

The oil was similar to that found at Barnesville and Temperanceville, and commanded the Pennsylvania price. The oil was derived entirely from the Berea sand, which has a thickness ranging usually from 30 to 40 feet. It varies considerably in texture, being sometimes fine and hard, and at other times coarse and soft. The good wells were found where the latter condition prevailed, the fine compact sand being as a rule dry. The interval between the Pittsburg coal and the Berea grit is reported to be 1,555 feet.

OTHER DEEP WELLS IN BELMONT COUNTY.

Wayne Township.—On the Bucher farm in section 32 a well was drilled to the Berea grit in 1900. After having been shot the well made a good showing of oil, but was never pumped and was abandoned. In 1901 a well was drilled to the Berea grit on the Barnes farm in section 28. The results were similar to those in the Bucher well.

Goshen Township.—On the White farm in section 33 a Berea well was drilled a few years ago. It made some gas with considerable salt-water, and was abandoned. On the Allen Bailey farm in section 32 a Berea well was drilled several years ago. It is reported to have made sufficient gas to throw the salt-water over the derrick. The gas was never used and the well was abandoned. A deep well has been drilled on the Warrick farm in the same section. It made a show of oil and gas in the Big Injun and a small show of oil in the Berea. On the Silas Bailey farm in section 31 a Berea well was drilled in 1900. The sand was 30 feet thick, but produced nothing but salt-water. In the spring of the same year a well was drilled to the Keener sand on the McNichols farm in section 32. The well was dry.

Kirkwood Township.—A well was drilled to the Berea grit on the White farm in section 30 a number of years ago. A show only of oil was reported, and the well was abandoned. On the Taggart farm in section 20 a Berea well was drilled in 1900. It made a show of oil and was abandoned. A well was drilled to the Berea on the Ann Drennan farm in 1900. It made some gas, but was abandoned.

Richland Township.—On the John Carlisle farm in section 5 two wells were drilled in 1900. One went to the Berea and the other to the Big Injun sand, but both were failures. A Berea well was drilled on the Chambers farm in section 2 in 1900, but the well was dry. On the Sutton farm in section 28 a well of unknown depth was drilled about 1896, but it was dry. On the Patton farm in section 23 a deep well was drilled, perhaps 10 years ago, but was dry. On the Milligan land in section 2 a Berea grit well was completed early in 1900. It is claimed that this well started at 25 barrels of oil per day, but it was soon abandoned. A deep well was drilled on the Neff farm in section 26 some years ago. It was a failure. In section 31 nine or ten Berea wells have been drilled. The first one was on the Stitt farm, and was drilled perhaps 12 years ago. It produced some oil and was pumped several years. In all, four producers were secured in this section. On the Clark farm in section 35 a Berea well was drilled about 1893, but was dry. On the Marshall farm in section 34 a Berea well was drilled about 1896, but it was dry. This is said to be the oldest well in the township. On the Burtoff farm in section 22 a Berea well was drilled in the spring of 1900, but was dry.

Smith Township.—In section 6 two deep wells, both dry, have been drilled. One was on the Mary Sutton farm, and the other may have been on the same place.

Pultney Township.—On the Wallace farm in section 6 a deep well was drilled in 1885. The Berea grit was struck at 1,550 feet and produced some gas, but not sufficient for commercial purposes. The well was afterwards extended to a depth of 2,700 feet, but with negative results. A well was drilled on the Reese farm in section 1 about 1896, but this, too, was a failure.

Pease Township.—A deep well, which was a failure, was drilled at Martin's Ferry about 15 years ago, and has already been reported.¹

An outline of the well record is given below:

	Feet.
Limestone	845 to 855
Salt sand and Big Injun.....	855 to 1,135
Berea grit	1,530 to 1,660
Bedford shale	1,660 to 1,745
Ohio shales	1,745 to 2,300

¹*Geol. Sur. of Ohio*, Vol. VI, p. 405.

Two additional wells, both failures, are reported in this township; one on the Thoburn farm in section 31, which went to the Berea sand, and the other on the Parker farm in section 1.

Washington Township.—Five wells have been drilled on the Isaac Welsh estate in section 11. The first two were drilled some distance below the Berea, which was found at about 1,700 feet. Number 1 showed some oil in the top of the Berea, but two or three feet lower a large quantity of salt-water was encountered, and this ruined the well. The Berea was about 25 feet thick. Number 2 did not show more than 8 feet of sand, and this contained a little oil. Number 4 made a good showing of oil in the Big Injun, but the Berea was dry. From 25 to 30 barrels of oil were pumped from the Big Injun sand in one week. The total depth of the well was 1,761½ feet. Well No. 5 made a good showing of oil in the Big Injun, but No. 6 did not do even that. In the fall of 1888 John McKeown drilled a well on the Armstrong farm in section 16, a record of which is given below:

	Thickness of formation. Feet.	Total depth. Feet.
Soil	10	10
Hard rock	20	30
Slate	20	50
Coal, Meigs Creek, No. 9.....	4	54
Slate	20	74
Limestone, hard, flinty.....	80	154
Coal, Pittsburg, No. 8.....	6	160
Slate, blue	30	190
Rock, red	25	215
Slate, blue	40	255
Rock, red	155	410
Slate, blue	100	510
Slate, blue with occasional sandy streaks	400	910
Sand, soft, gray.....	100	1,010
Salt sand, white, hard, changing to blue	158	1,168
Slate	8	1,174
Big Injun sand.....	319	1,493
Slate	130	1,623
Sand, hard	25	1,648
Slate, white	25	1,673
Sand and slate, soft.....	25	1,698
Slate, blue and gritty.....	124	1,822
Berea sand	16	1,838
Sand, coarse, black and very soft.....	16	1,854
Slate, red and sandy.....	60	1,914
Slate, dark, gritty.....	150	2,064
Sand	15	2,079
Slate, blue	50	2,129
Sand and shale, dark gray.....	75	2,204
Sand	30	2,234

Some gas was found at a depth of 20 feet in the Salt sand, and much salt-water at 100 feet. Salt-water was found in the upper part of the Big Injun sand, and a show of oil near the middle of the formation. The Berea was dry. In no other well thus far drilled in Ohio has there been reported the well defined sand beds below the Berea that were found in this well. These strata, however, produced neither oil nor gas. A well drilled on the Hendershot farm in section 9 made a small show of oil in the Big Injun. The total depth of this well was about 1,450 feet. Wells have been commenced, but owing to accidents have not been completed on the Vanduyne farm in section 4, the Bright farm in section 27 and the Workman farm in section 19. For the information concerning this township the Survey is indebted to Hon. E. B. Armstrong.

Yrok Township.—A well has been drilled on the Dorsey farm in section 27, and reached a depth of 2,200 feet. The sand was reported of fine quality. It made a show only of oil, but contained much salt-water. Two deep wells have been drilled in section 20, one on the Boyer farm reaching a depth of nearly 2,300 feet, and making a good showing of oil, and the other on the Dorsey and McMurray farm reaching a depth of 2,200 feet, but entirely dry. A dry well having a depth of 2,100 feet has been drilled on the Ramsay farm in section 8. On the Dorsey heirs farm in section 2 a deep well has been drilled. The depth of this has not been learned. It is claimed to have made a good showing of oil. For the facts concerning this township the Survey is indebted to A. A. Caldwell, of Captina.

Wheeling Township.—In 1902 two wells were drilled near the village Uniontown, and each made a good showing of oil, and with it much salt-water. The Berea sand was found in one at a reported depth of 1,546 feet and in the other at 1,610. The oil was of inferior quality, and the wells were abandoned.¹

GUERNSEY COUNTY.

The exploration for oil and gas in this county has been long continued and extensive. As stated by Dr. Orton in Volume VI, the search about Cambridge was more than ordinarily interesting. This resulted from the presence at that place of the Cambridge anticline, and hence of the existence of the rock structure regarded as very favorable for oil and gas accumulation. Drilling began about the time of the greatest excitement at Findlay and adjacent towns favorably situated in the great Trenton limestone field, and has been continued from time to time to the present day.

A thorough test has been made of the anticline at Cambridge, and also north and south of this place. The results have been unfavorable. The Berea sand has been struck many times and found to have a thickness and texture suitable for oil and gas, but notwithstanding the favorable

¹Since the above was written a small pool of oil has been developed in this locality.

combination of these circumstances the products desired have been conspicuous either by their absence or are present in such small quantities as to be of little value commercially.

On the Waller farm near Cambridge 7 shallow wells were drilled, which produced a small amount of oil, but were abandoned. The oil is said to have been of such a nature that the Standard Oil Company would not handle it. The Cambridge Light and Fuel Company has 3 producing gas wells in Cambridge township. These were drilled several years ago, prior to 1892. The rock pressure at present (1900) is reported to be 400 pounds, but the production of the wells about 100,000 cubic feet only per day. There is considerable trouble from salt-water and it is estimated that when the pressure drops to 200 pounds the wells will have to be abandoned. A ~~small oil well~~ was secured in the Berea sand on the Black farm, West Cambridge, in 1899. The sand was struck at 1,098 feet below the surface, and the gas pressure was sufficient to flow the oil. Such discoveries as this simply lead the operator to make further and further tests with the hope of securing a valuable pool.

While expectations have not been met around Cambridge, a valuable reservoir of gas has been found 4 miles south of that city in Jackson township. This is known as the Harmony field. It was opened in 1892 by the Pebble Rock Oil and Gas Company, the first well having been drilled on land of Margaret Murray. The well was closed until 1893, when it, together with all the leases held by the same company were bought by the Cambridge Light and Fuel Company. The latter now has 6 producing wells in the field. Later the United Gas Company extended the territory and now (September, 1900) has 8 producing wells. The Campbell and Buckett Oil and Gas Company has 4 wells in the field, the product of which is piped to Byesville where it is used as a fuel by the Art Glass works. Doubtless other wells will be drilled and the production of the field correspondingly increased.

The Harmony reservoir lies on a low dome shaped uplift. This is made plain by the Cambridge or No. 7 coal which rises above drainage in the central part of the territory, but dips away in all directions from this. It was the existence of this dome which led to the drilling of the first well, and thus to the discovery of the reservoir. The gas sand is the Berea, and lies from 1,080-85 feet below the Cambridge coal. It is not a continuous bed of sandstone, but is separated by a few feet of slate as follows:

	Feet.
Sandstone (gas).....	40
Slate	4
Sandstone	20

The gas is found above the slate. At the junction of the gas sand and the slate water is encountered, and so the former is rarely drilled through. Occasionally a little oil and gas are found in the sand below the slate, but none of the wells in the Harmony field derive their supplies from

this horizon. The sand varies considerably in structure. Sometimes it is coarse and porous, and at other times fine and hard. The wells are shot ordinarily with from 25 to 30 quarts of nitro-glycerine. The rock pressure of the field was originally about 500 pounds, but has now decreased to approximately 400. The largest wells produce from 1,000,000 to 2,000,000 cubic feet per day.

The Cambridge Light and Fuel Company charges 15 cents per thousand for the gas. Besides a large number of families the company supplies the local plant of the American Steel Sheet Company, which uses about 2,000,000 cubic feet per day. The Cambridge Art Pottery Company, now in process of erection, expects to use gas, thus making another large draft on the field. The United Gas Company makes the same rate as the Cambridge. It supplies Cambridge, Byesville, Pleasant City, Hartford, Quaker City, Barnesville and Caldwell. However, several of these places derive their supply from the Dudley field. This company supplies the water works and electric light plants at Cambridge, and the glass houses at Quaker City and Barnesville.

Since the above was written in 1900, much drilling has been done in the Harmony field, with the result that the territory has been considerably extended. Later wells, however, were small, and the heavy demands have greatly decreased the rock pressure of the field. The supply is no longer adequate for the factories, and the same is true for domestic purposes. Had the fuel been restricted to the latter use the supply would have been ample for years.

Besides the exploration around Cambridge and in the Harmony field a large number of deep wells have been drilled in other parts of the county. These are as follows:

Londonderry Township.—One Berea well in section 2, making 4 barrels of oil per day.

Jackson Township.—Two Berea wells on the Siens farm in section 7. Both are small producers.

Town of Senecaville.—About 1897 a well drilled at the edge of this village found oil at a depth of 162 feet. It produced 10 barrels the first day and none thereafter. The oil was sold as a lubricant. Other wells were drilled in the same vicinity, but all were failures. Many years ago a shallow well was drilled along Seneca creek, and the oil secured sold as "Seneca oil."

Quaker City.—A well was drilled to the Berea in 1886. The sand was found at a depth of 1,341 feet, and was 6 feet thick. It produced a small flow of gas. Other wells have since been drilled in the same vicinity but without securing returns that compensate the operator.

Kimbolton.—Two wells have been drilled near this place, one in 1887 and the other soon afterwards. The first was a failure, but the second produced a moderate flow of gas, the rock pressure having risen to 300 pounds or more.

NOBLE COUNTY.

The discovery of oil in this county, as in several others in the state, resulted from drilling for salt. Early in the nineteenth century, perhaps in 1814, a well drilled to the depth of about 350 feet on the Caldwell farm, now the Moore, near the county seat, found a supply of oil. This discovery, however, was made too early; for at that time there was no demand for the product, which, in fact, was regarded as a nuisance, since no well in which it was found could be used for salt. The well in question is reported to have flowed periodically, and the oil to have been used for lights and as a lubricant, but it was too thin for the later purpose. It is probable that other wells in the same vicinity gave similar results, but the oil secured was a matter of accident. Not until the discovery in Pennsylvania, in 1859, did the search for oil begin. In that year George J. Duff, of Pittsburg, began leasing land along Duck creek. The first territory secured is said to have been at Dexter, where there was a show of oil in the creek. Later he leased the land near Caldwell, that contained the old well. Most of the leases written at that time guaranteed the land owner a royalty of one-fourth of the oil secured.

About 1860 drilling began along Duck creek between Caldwell and Macksburg. Just east of Caldwell two small, but valuable producers were secured. One of these is reported to have been 98 feet deep, and to have produced oil of 26 degrees B. gravity. The depth of the second well is not definitely known, but it is reported to have been deeper than the first one, perhaps from 250 to 300 feet. The gravity of the oil secured from this well was 34 degrees B. The product was hauled in barrels to Lowell, and then shipped by boat to Pittsburg. It is reported that \$15,000 worth of oil was sold from these wells.

In the fall of 1860 (probably) a well was drilled on the Spears land about one mile south of Caldwell. At a depth of approximately 68 feet a strong flow of oil was secured. Adequate preparations for storing the liquid had not been made, so that much ran into the creek and was lost. It is estimated that this well produced 6,000 barrels. From that early time to the present, oil has been secured from the valley of Duck creek in the southern part of Noble county. By far the best part of the territory is that lying between Dexter City and Macksburg, but it forms the northern part of the Macksburg field and has already been considered.

Around Dudley, Olive township, nearly 40 wells have been sunk to the Berea since the fall of 1897. The excitement began when the John S. Dunn Company secured a 14 barrel producer on the land of Rebecca Tilton. The best well reported is Brown No. 2, drilled in 1898. It started at between 35 and 40 barrels, and flowed during a year or more, and now (September, 1900) is being pumped. On the average the wells start at 10 barrels per day. The number of producing oil wells in this pool in

1900 was 12. The oil, however, is not the most valuable product. There are 8 gas wells which have a high pressure and supply large quantities of fuel to surrounding towns.

According to Orton Dunn, the A. J. Ward gas well, completed April 13, 1899, had an initial rock pressure of 736 pounds per square inch, and an open pressure of 35 pounds through a 3-inch aperture. The top of the sand was found at a depth of 1,380 feet. After drilling 9 inches in the sand the pressure became so great that the drill could not be forced down further. The well was not shot. This supplies 200 families at Caldwell; 41 at South Olive; 120 at Dexter City; 40 at Elba, and about 25 farm houses along the line. Besides these it supplies 28 boilers for drilling and pumping. The Fulton Caldwell gas well No. 2, completed January 12, 1899, had an initial rock pressure of 730 pounds. On August 31, 1900, it had dropped to 385 pounds. Besides the John S. Dunn Company, the United States Company reaches this field and pipes the gas to Caldwell, Barnesville, Quaker City, Cambridge, Byesville and Pleasant City. The Charter Oil Company, which formerly entered the territory, has sold its wells to the United Gas Company.

The gas rates in Caldwell are as follows (1900):

The United Gas Company makes a monthly rate of 50 cents per fire for a No. 5 mixer. For all illuminating purposes 15 cents per light is charged, but 50 per cent. of this is paid to the corporation for the privilege of entering the town. This charge is made to protect the Electric Light plant, owned and operated by the town. The John S. Dunn Company makes a rate of \$12 per year for the first fire; \$6 for the second; \$2 for the third, and \$1 for the fourth and each additional fire. These rates are for the No. 5 mixer. The company makes five-year contracts.

More recently a number of gas wells have been secured northeast of Dudley, and these supplement the supply received from the latter place.

At Moundsville in section 36 of Olive township, two Berea wells have been drilled. One of these was dry, but the other struck a large body of gas having a rock pressure of 650 pounds. Near Belle Valley some drilling has been done in recent years. Four producers have been secured, the first one in 1897. This started at 5 barrels per day, and still flows from 3 to 4 barrels. The remaining wells have a similar production, though two of them require pumping. The sand is the Berea, and lies 1,300 feet or more below the surface. It is very regular, the thickness ranging from 15 to 18 feet. Where oil is not found, salt-water is, and the latter is common in the thicker parts of the sand. The wells are cased through the Salt sand. An effort has been made to extend the producing territory both north and south, but as yet without success. Thus 6 dry holes have been drilled in sections 17, 18 and 19; while from 2 to 3 miles southeast from Belle Valley, failures are recorded in sections 33 and 34. In the extreme southeast corner of Jackson township a large number of

wells have been drilled to the 500-foot sand, but this territory forms a part of the Macksburg field, and has already been considered in that connection.

HARRISON COUNTY.

This county has been extensively tested for oil and gas, but doubtless much work remains to be done. The oil already secured has contributed directly and indirectly much to the wealth of the community, and it is not unreasonable to expect that this will be an important source of revenue to the county during a considerable period in the future.

The pools secured thus far (1903) are the following:

- | | |
|-------------|-----------------------|
| 1. Cadiz; | 5. Jewett; |
| 2. Bricker; | 6. Scio; |
| 3. Snyder; | 7. Bowerstown; |
| 3. Maxwell; | 8. Philadelphia Road; |
| | 9. Plumb Run. |

Geographically considered they may be classed in two groups, the last five named making one, and the first four the other. In this discussion of the pools will be considered in this relation rather than in that of priority of discovery.

The surface strata in this county lie almost entirely in the Conemaugh or Lower Barren and the Monongahela or Upper Productive Coal Measures. Along the western side of the county the Upper Freeport or No. 7 coal, which lies just below the Lower Barren Measures, is found a short distance above drainage, while in the southeastern corner of the county, the Pittsburg or No. 8 coal, which makes the base of the Upper Productive Measure, is not far above drainage.

THE CADIZ POOL.

Discovery and Development.—In the summer of 1887 the Cadiz Oil and Gas Company drilled a well on the R. R. Cochran farm one mile north of the court house, the work having been done by Scott Watson of Braddock, Pa. His compensation was \$1.25 per foot, but he was required to furnish casing, machinery, fuel, etc. When the Salt sand was reached a heavy flow of brine was liberated which ran from the top of the well, and the Berea sand, which was struck at a depth of 1,414 feet and was 50 feet thick, yielded neither oil nor gas. The company, however, was not demoralized by this failure, but in the fall of the same year began drilling a well on the farm of W. D. Rogers in the southwest quarter of section 29, of Cadiz township. This well was located not because of any indications of the presence of the desired products, but to hold certain leases on large tracts which the company had in that vicinity. Work continued until the Berea sand was struck, but the little gas found did not warrant piping the well, and accordingly it was abandoned.

The second failure dampened the enthusiasm of the company but did not stop the work. However, at this stage counsel was sought, and had the information received been applied, the company would have secured two fine pools of oil which would have radically changed the profit and loss columns of the company's books. At the request of the company, the State Geologist, Dr. Edward Orton, visited the territory during the holiday vacation of 1887, and, from reports received from reliable citizens, ran several lines east and west from Cadiz to determine the arrangement of the strata, or in other words to locate, if present, anticlines and terraces, which he regarded essential to the production of oil or gas in large quantities. A preliminary survey was made with the aneroid barometer, and the principal variations in the dip noted, and then a surveyor was employed to run levels over the most promising territory. A report was made by the Geologist to the company early in January, 1888, but this seems to have been lost. Fortunately the citizens of Cadiz still remember distinctly the nature of the report, and besides the information secured in this manner the following paragraph taken from the Cadiz Republican, January 19, 1888, shows conclusively that Dr. Orton had determined the anticline of the region: "Professor Orton has furnished maps and drawings of this region of country to the Cadiz Gas and Oil Company, which show that the anticline of the region is to the east of the town. It is therefore well settled Geologically, that if either oil or gas is to be found here it must be found in that direction. The first two wells which the company have sunk were therefore in locations in which there was no hope of finding oil. The next well will be sunk in the right location from a Geological standpoint. Whether gas or oil will be struck there, of course, is an unsolved problem." The reports made by citizens of Cadiz are even more specific; they state that not only did he locate the anticline, but that he foretold the two places on it where conditions were most favorable. One of these is now occupied by the Bricker pool, and the other by the Snyder. In the former he stated correctly in what part oil and in what part gas would be found. In the latter pool, however, the tract which he regarded most favorable lies about a quarter of a mile east of the best wells. It is, however, within the producing territory. He advised against drilling west of Cadiz, but notwithstanding this numerous holes have been sunk, all of which have been failures.

A short time after the receipt of Dr. Orton's report the company began drilling another well, the location being on the Boggs heirs' farm in the southwest corner of section 29, Green township. This territory was within the area which Dr. Orton reported favorable, though he did not regard it as the most promising locality. The well made a good show of gas, the closed pressure being 150 pounds per square inch, but no oil. Salt-water was abundant, running from the top of the well. In June the company completed its fourth well, the Berea having been struck at about

1,400 feet. This was located on land of G. Fryer in the northeast quarter of section 34 of Cadiz township, and was within the territory reported favorable by the State Geologist. A small flow of oil and considerable gas were secured. The latter was allowed to escape for a year or more, and then the well was closed when the rock pressure rose to 250 pounds per square inch. The gas has been used for more than ten years, and in the fall of 1900 the production was 25,000 cubic feet per day.

On July 7, 1888, the company held a meeting to decide future action. Steps were taken to increase the capital stock from \$10,000 to \$30,000, but this seems never to have been accomplished. Four consecutive failures were too much for the organization, and the company gave up the search, having gained considerable in experience if not in wealth. Why, it may be asked, did not the company follow more closely the advice of the expert whose counsel it sought? The answer is simple, though ludicrous: The company did not hold leases on the territory which Dr. Orton regarded most promising for oil or gas, and though the land holders would have gladly granted the leases without expense to the company to have their farms tested, the company absolutely neglected to secure the leases, and so failed to test the territory where they were told their chances would be best. The discovery later of valuable pools of oil in the localities referred to is a fitting rebuke to the carelessness of the old company.

In the fall of 1888 a new organization, "The Berea Grit Oil and Gas Company" was formed. Its capital stock was \$20,000, and its object was to test further the territory around Cadiz. Shortly after the company was organized it began drilling on the farm of H. Morgan near the north line of section 33, Cadiz township. This is near the gas well drilled by the old company, and so is within the territory regarded as promising by Dr. Orton. A small show of oil was secured, but not enough to warrant pumping, unless other wells were secured. Within the following winter (1888-9) a well was drilled on land of E. G. Holliday, one-half mile east of the Morgan well. After having been shot with 30 quarts of nitro-glycerine the well made five barrels per day. In the summer of 1889 a well was drilled on the A. J. Petty farm, adjoining the Holliday on the east. This time a small production of both oil and gas were secured, and the well still (1901) yields each in about the same quantity as when first drilled. In the autumn of 1889 a well was drilled on the D. Norman farm which joins the Holliday. After having been shot with 60 quarts of nitro-glycerine the well produced 8 barrels of oil per day, and the lasting power of the sand was such that 12 years later it was yielding two barrels per day.

The poor success discouraged the company, and no further drilling was done for some time. The organization, however, still exists and has three producing wells in the pool. A half dozen or more wells have been

drilled since 1889, but nothing better than small producers have been secured. In 1901 there were 8 oil and 2 gas wells producing in the field. The pool has a length of less than one mile, and a maximum width equal to the length. The pool lies in the two townships, Cadiz and Green, including the southeast quarter of section 34 and the northeast quarter of 33 of Cadiz, and the southwest quarter of section 28 and the northwest quarter of section 27 of Green. The producing sand is the Berea, which may be regarded as in normal condition. The oil is found near the base of the formation.

One good act of the "Berea Grit Oil and Gas Company" was to secure the Fryer gas well, and pipe the fuel to Cadiz giving that place its first experience with natural gas. This was sold for fuel at 75 cents, and for light at one dollar per thousand feet. Since April, 1901, there have been rival companies supplying the town with gas. These are (1) The Cadiz Gas Company, and (2) T. N. Donaldson. The first company derives its gas from the Fryer wells, and supplied 300 families during the winter of 1900-1. The charge until April 1, 1901, was 75 cents per thousand feet, regardless of the use made of the gas, and since then the rate has been 25 cents per thousand feet. The second company derives its gas from the Jewett field, five miles north of Cadiz. In July, 1901, the company was supplying 50 families in Cadiz, its rate being the same as that of the other company.

THE BRICKER POOL.

This lies almost wholly in the eastern half of section 30 of Green township, and as developed in 1901 did not exceed one-half mile square in area. The pool is surrounded by dry holes, and so the productive territory cannot be greatly increased.

The oil was discovered in October, 1899, by the Bricker Oil Company, which drilled a well on the Bricker farm. The Berea sand was found charged with oil, the well flowing 125 barrels per day for a short time, making 13,040 barrels during the first 120 days. Other wells were begun at once, and drilling has been in progress ever since. The initial production has ranged from 8 to 125 barrels per day, several having started at the last mentioned figure. The compensation of the driller in this pool is 60 cents per foot, the operator furnishing everything¹ except fuel, or 70 cents when the driller furnishes boiler and engine. The wells are cased through the Salt sand.

The producing sand is the Berea. This is almost always found, but presents several interesting characters. The top of the formation is a fine grained sandstone which for some reason has been named a lime by the oil men. It has commonly a thickness of 18 feet, and really is the cap of the Berea. Below this in the Bricker pool is the pay-rock, having

¹This does not include casing.

a thickness usually of 8 or 9 feet; this is succeeded below by a thick bed of sandy slate, and this in turn by about 10 feet of sandstone. A generalized section for the field is as follows:

	Feet.
Cap-rock, the "lime" of the driller.....	18
Pay-rock	8-9
Sandy slate	25
Sandstone	10

Other drillers, however, report the bed of sandy shale much thinner, and the stratum above correspondingly thicker. This results from the different ideas of what constitutes a sandy shale and a true sand rock, and in part from the varying thickness of the bed in question. The stratum is sometimes reported to disappear entirely.

The Pittsburg coal is found near the hill tops and the interval between this and the Berea sand is about 1,475 feet. The wells on the northwest side of the field produce much gas, while those on the southeast yield little, but contain much brine. A number of the wells flowed at first, but usually they had to be pumped after a few days. Well No. 1 on the Bricker farm flowed 9 months or longer. This well which was completed in October, 1899, had an initial production of 125 barrels; in July, 1901, it was pumping 20 barrels per day, thus indicating the lasting quality of the sand. The wells are shot usually with from 40 to 80 quarts, and some have already been shot the third time. The oil has a gravity of 46 degrees B., an amber color, and commercially is classed with the Pennsylvania product.

The pool lies on the eastern slope of a low anticline, and as has already been stated is one of the places where Dr. Orton reported conditions most favorable for oil production. The testing of the territory in 1899 appears, however, to have been independent of his report. The drillers do not discriminate between the Salt sand and the Big Injun. In fact the two are not sharply separated here as they are farther south, the "Big lime" not being recognized farther north than the extreme southern part of Belmont county.

THE SNYTER POOL.

This is located in the southern half of section 20 and the northeast quarter of section 19 of Green township, the productive belt, as developed in July, 1901, comprising less than one-half of a square mile. The number of producing wells at that time was 25.

The pool was discovered in the spring of 1900, the first well having been drilled on the William Croskey farm. A small well was secured, and is still being pumped. The next location was on the Snyder farm, immediately to the west, and a 25 barrel well was secured. Drilling has been in operation since that time and while the pool does not give promise of developing into a large one, it may be considerably extended on the west.

The producing sand here as elsewhere in the county is the Berea. The formation is similar to that in the Bricker pool, so what has been said concerning the sand of that place applies equally well here. The following skeleton record of Norman well No. 1 shows the relative positions of the principal formations:

	Feet.
Pittsburg coal at.....	12
Coal	592
Coal at.....	672
Coal at.....	825
Big Injun sand at.....	970
Bottom of sand at.....	1,050
Top of Berea ("lime" of the driller).....	1,487
"Pay" in Berea.....	1,501
Bottom of well.....	1,512

The seam of coal lying about 580 feet below the Pittsburg is reported by the drillers everywhere in the Snyder and Bricker pools. The thickness assigned to it varies from 6 to 11 feet, but these figures must be taken with much allowance. Black shales, impure coals, and good coal are likely to be confused by the driller, and hence his figures are usually too high. It seems very probable, however, that a good seam of marketable coal lies at this horizon. This may contribute more to the future wealth and comfort of the county than the Pittsburg seam does at the present time.

The largest well secured thus far (July, 1901,) had an initial production of 30 barrels per day. The oil is similar to that of the Bricker pool, and hence commands the Pennsylvania price. The productive territory forms a part of that reported favorable by Dr. Orton.

Outside of the pools already considered, a number of wells have been drilled to the Berea in Green township. On the Croskey farm near Unionvale in section 17 a well made a small showing of oil; on the Black farm near the center of section 18 a dry hole was drilled; on the Houser farm in the southeast quarter of section 14 a dry hole was drilled. This is about one mile east of the Snyder pool; on the Copeland farm near the middle of section 15 a dry hole was drilled; on the Howell farm in the southwest quarter of section 16 a dry hole was drilled; in the northeast quarter of section 21 three dry holes have been drilled on the Copeland farm, and a small oil well in the northwest quarter of the same section on the Hanna farm; also a dry hole in the southwest quarter of the same section on the Copeland tract; in the southern half of section 22 two dry holes have been drilled, one on the Croskey and the other on the Clifford land; a small showing of oil in a well on the McGavvan tract in the north half of section 26; a small well on the Hanna land in the northeast quarter of section 27. This list of failures does not include those which may be regarded as mark-

ing the limits of the productive pools. It may be well to remark here that the southeastern corner of the Jewett pool lies in section 28 of this township.

THE MAXWELL POOL.

This lies in Short Creek township, and is confined almost wholly to the southwest quarter of section 21. In July, 1901, the number of producing wells was less than a dozen, and from the dry holes which almost surround the pool, it appears that the productive belt cannot be materially extended. The pool was opened in the fall of 1899, the first well starting at 5 barrels. Work has been in progress since that time, and doubtless several wells will yet be drilled. The largest producer started at 20 barrels per day.

The oil is found in the Berea below the cap-rock, as is the case in the Bricker and Snyder pools. The oil has a gravity of $42\frac{1}{2}$ degrees B., and a light amber color. Its characteristics are similar to those of the Cadiz pool, from which it is a half mile only distant. The gas present was sufficient to cause several of the wells to flow when first drilled, but all soon had to be pumped.

Other Wells in Short Creek Township.—Two dry holes have been drilled on the Giffin farm in the northeast quarter of section 26; a dry hole on the Yost farm in the southwest corner of section 5; a dry hole on the Shields farm in the northwest quarter of section 1; a well making much brine, but nothing else on the Hogan farm in the southeast corner of section 2; a dry hole on the Branson farm adjacent to the village Georgetown; a dry hole on the J. F. Hanna farm in the northwest quarter of section 13; a dry hole on the Stephens farm in the southeast corner of section 15; a dry hole on the J. N. Hanna farm in the southeast corner of section 24.

THE JEWETT POOL.

This is situated in the townships Archer, Green and Rumley. The principal part of the producing territory lies in section 34 and the southern half of section 35 of Archer township. Beyond this it extends into the southwest quarter of section 28 of Green and northward into section 35 of Rumley. The pool is well enclosed by dry holes on all sides except the south, and hence there is little prospect of extending the producing territory except in the one direction.

The pool was opened in the fall of 1895, the well having been drilled on land of A. M. Busby in the southern half of section 35 of Archer township. The well produced gas which was piped later to Jewett, and was not abandoned until the fall of 1899. A short time later another well was drilled on the same farm, and this also produced gas. Thus far the work had been done by the Jewett Oil and Gas Company, a local organization; but in the spring of 1896 this company transferred a large strip of territory

to the Ohio Oil Company, which drilled on the Busby farm and secured a 10-barrel well. From that time there has been slow but steady development. In July, 1901, the number of producers was approximately 75, of which 8 were gas wells. The companies operating in the territory at the date mentioned were the Ohio Oil Company, the Scott Oil Company and F. N. Donaldson.

The oil and gas are derived from the Berea sand, which has a thickness of about 40 feet. The pay-rock lies near the bottom of the formation and has a thickness of from 3 to 12 feet. The oil wells have commonly started at from 8 to 10 barrels, and so are regarded small, but the yield is maintained with persistence. The oil has a gravity of 45 degrees B. An important part of the field is the gas territory, of which there are two parts, one along the southeast border of the territory and the other along the northwest margin. The daily production of these had not been measured when the territory was visited, but the closed pressure on the northwest side of the field was reported at 450 pounds, and that on the southeast at from 250 to 300 pounds per square inch. The production of these wells is piped to Jewett, Cadiz and Scio.

The wells all produce some salt-water in the Berea, and usually much in the Salt sand and Big Injun. The casing extends through the latter formation. The strata in the principal part of the field dip to the northwest, and so lie on the western slope of an anticline. The Bricker and Snyder pools lie on the eastern slope of the same anticline. The gas wells on the northwest side of the field indicate that the rock is rising northwestward in that region.

THE SCIO POOL.

Location and Area.—The pool lies principally in North township, including in whole or in part sections 3, 9, 2, 33, 32, 1, 31, 26, 25, 30, 36 and 35; beyond this it extends east into Rumley, occupying parts of sections 13, 18, 19 and 24; at the extreme north the pool crosses into Carroll county, but this tract is so small that it is of very little importance. The producing territory extends northwest and southeast, and is triangular in shape, the base lying to the south. The maximum length of the field is about 5 miles, and the maximum width three miles.

Discovery and Development.—The search for oil in this locality began 30 years ago. As early as 1872 a number of derricks were standing along the edge of the village. One of these was on the Spiker farm, and was drilled by the old-fashioned spring pole method, an entire summer having been consumed in the work. These wells did not go beyond the Big Injun and so nothing but salt-water was secured. It is interesting to note that one of these wells was drilled by H. A. Snyder, who more than 25 years later organized the Scio Oil and Gas Company, which opened the pool. Equally interesting is it to report that the Spiker farm on which one of

these wells was drilled, became later one of the most valuable tracts in the field, more than \$450,000 worth of oil having been secured from it. The early attempts failed simply because the drill did not go deep enough.

The discovery of oil near the neighboring town of Jewett in 1895, appears to have encouraged Snyder to renew the search in the vicinity of Scio. He accordingly began taking leases for oil purposes and secured options on about 2,000 acres near the village. His next step was to organize a company to test the territory, and in March, 1898, the Scio Oil and Gas Company was incorporated with a capital stock of \$10,000, divided into shares of \$25 each. The people, however, had little faith in the venture, and consequently the stock did not sell rapidly. Only 56 shares were disposed of, and even after the first well had been drilled and oil secured, there was difficulty in inducing the stockholders to double the amount already paid. This however, resulted more from their inability rather than from their lack of confidence in the project. After the second well had been completed the stockholders decided to double again their subscriptions, making necessary a payment of \$100 for each share originally taken. The amount of money raised by the three assessments combined was \$5,600. The company drilled two additional wells and put up rigs for two more, and then sold out to Myers and Brown for \$100,000.

When the Scio Oil and Gas Company was organized, Snyder transferred to it his leases, the consideration being 4 per cent. of the oil secured and 2 per cent. of the gas, after the land holder had received his royalty. Much of the territory covered by these leases was dry, and other tracts were forfeited by the non-payment of rent. Nevertheless Snyder received a handsome fortune in return for his perseverance.

The first well drilled to the Berea sand in this pool was located on a small tract of land owned by Matthew Henry, situated one-fourth of a mile north of the village. The well was completed June 7, 1898, and after having been shot with 80 quarts of nitro-glycerine, began producing 18 barrels of oil per day. The second well, located on land of William Donaldson, started producing 22 barrels, but the necessary tanks not being at hand the well was left idle several days, the tools hanging in the well. When these were removed the well began flowing, and the gas catching fire from the boiler burned the derrick. This accident was widely published, and as is usual under such circumstances, the production of the well was exaggerated. The accident attracted the attention of oil men from near and far, and started a boom which in a short time revolutionized the village.

The third well was drilled late in the fall of 1898, on a lot owned by Jacob Strayer within the corporation limits. This began producing 75 barrels per day, and of course added fresh fuel to the excitement. After this wells were completed in rapid succession, and all were producers. Early in December the leasing of town lots began, and wells by the score

PLATE V



SCIO DURING THE BOOM

were soon drilled on them, the owners vying with each other in their anxiety to have their property tested. Before tracing further the development of the territory let us consider the changes which the discovery of oil made in the village.

Before the discovery of oil Scio had a population of about 900, composed largely of retired farmers and others in well to do circumstances. It had long been a favored place for retired Methodist ministers who moved there because of the advantages which the college offered their children, as well as for the healthfulness of the location, the moral tone of the community, and the pleasant social conditions. The village had no manufactories, but derived its support from the students and the farmers of the surrounding country. Once only in 18 years was there a saloon in the town, and that one was soon driven out by the angry citizens. Billiard halls and bowling alleys were conspicuously absent, while card parties and dances were in bad repute. The discovery of oil worked the most sudden revolution ever seen in an Ohio town. The population of 900 in 1898 increased with amazing rapidity, and it is estimated by Prof. J. H. Beale, of Scio college, that in the following January and February it had risen to 12,000, though other well informed persons put the figure considerably lower.

The people came principally from the oil fields of Pennsylvania, West Virginia and Northwestern Ohio, and consisted of operators, drillers and teamsters; with them came those who supplied the necessities of life, boarding-house keepers, hotel men, butchers, etc. But with those necessary to develop the territory came a large number who maintained themselves by preying on the weaknesses of men,—the fakir, gambler, saloon keeper and dissolute woman were conspicuously present. There were 11 saloons in the town and an unknown number of "speak-easies." Three or four variety theaters were started, and the nights were made hideous by the barkers of all kinds. These features so horrified the staid citizens that they sold or rented their property and moved away. The village was unable to care properly for one-tenth of the people who had so suddenly gathered there. They lived in tents, shanties, reconstructed stables, boiler houses, or wherever they could find shelter. Many slept in chairs. Hundreds unable to find lodging left on evening trains for near by towns, returning the following morning. Finally the Pennsylvania railroad put on an extra train to accommodate the crowds. It ran between Pittsburg and Dennison, and was popularly known as the "greaser," because its patronage consisted largely of oil men. Rooms which previous to the excitement rented for 60 cents per week commanded from five to ten dollars for the same period.

The macadamized streets of the village were soon cut through by the heavy loads of oil supplies, and converted into mere mud canals, in many places so deep that the axles of an ordinary wagon would drag. It

was not uncommon to have horses mire in the deeper places, and have to be pulled out by another team.

The demand for men and teams was of course very heavy, and exorbitant rates were charged. Forty dollars a day were frequently paid, and one operator reported having given twenty dollars to have an ordinary boiler dragged 60 feet. The two railroads greatly increased their siding to accommodate the cars loaded with boilers, rig timbers, engines, machinery, etc. It was not uncommon to have supplies remain on the cars 10 days before they could be unloaded, so great was the rush.

As the number of wells increased the danger of fires became so great that nearly every policy in town was revoked, but later several companies took risks on what were regarded choice locations, charging as high as \$100 per month, where from \$5 to \$6 per year had been charged before. Several large fires occurred and when the danger was at its height, a number of public-spirited citizens began the construction of a system of water works, which however, was not completed until the greatest danger was past. The cost of the plant was about \$30,000.

It is hardly necessary to state that the general conditions then existing were very disastrous to the college. In 8 weeks time the attendance dropped from 300 to about 25, and all departments of the school except two were moved to New Philadelphia, 24 miles distant. After about 4 months, however, these were taken back to Scio.

The time of greatest excitement was during the first 3 or 4 months of 1899, when there were 75 strings of tools at work. After that a decline set in, and this was almost as rapid as the growth of the boom. The village, however, did not drop back to quite its former condition, the population in 1901 being between 1,200 and 1,300. An immense amount of money was left in the community, and the wells will be an important source of revenue for a number of years.

Of the early companies in the field, one of the most active was the Allegheny. After having drilled 26 wells in and around Scio, the company sold a part of its property to the United States Oil Company for \$455,000, an exorbitant price, and later sold the remainder to the Consolidated Oil Company for an unknown sum. The most extensive operators in the field were the E. H. Jennings Brothers and Company, of Pittsburgh, who have had about 140 wells, nearly all of which are still producing (1901). While nearly all the land holders leased their property for a royalty of one-eighth the oil, occasionally a farmer operated his territory himself. This was true of the Hogue Brothers who drilled 47 wells on 160 acres, and all are still producing. The Pennsylvania and Wheeling and Lake Erie tracks run side by side through the south side of the field, and in the height of the excitement the right of way of these companies was leased and wells drilled on it about every 400 feet. The principal operators in the pool have been the following:

The Scio Oil & Gas Company.
Myers & Brown.
The Allegheny Oil Company.
Lecompt, Bruner & Company.
E. H. Jennings, Brothers & Company.
The Hogue Brothers.
Bailey & Robinson.
W. H. Milliken.
Conotton Valley Oil Company.
John Mildren.
C. R. Mildren & Company.
Jennings, Groves & Company.
Nassau Oil Company.
O'Day Brothers.
The Ohio Oil Company.
F. N. Donaldson.
Boyer & Caldwell.
Rhodes, Wilson & Reynolds.
Genesee Oil Company.

According to the guager for the Buckeye Pipe Line the largest number of producing wells in the field was in January, 1900, and numbered about 850. The total number of wells drilled in the field is about 1,000. Of these perhaps 220 were drilled within the corporation limits, but only about 20 of that number are still producing (1901). From a financial standpoint nearly all of the village wells were failures owing to their having been drilled so close together. A few, however, were very profitable: Thus one on the Given lot is reported to have produced \$30,000 worth of oil. Three were drilled on the college campus, but the royalty derived was not large. The average cost of a complete well in the field was about \$3,000.

The oil has been purchased and shipped by three companies,—The Buckeye Pipe Line, the Sun Oil Line and the National Pipe Line. The former was the first to enter the field, having begun pumping in December, 1898. It has shipped as high as 8,000 barrels in one day, but the average has been much less than this. In July, 1901, the average was about 1,100 barrels per day. The company has 3 tanks, each of 1,200 barrels capacity. From these the oil is shipped through two three inch lines, but about four miles east of Scio one of these changes to a four inch. These carry the oil to Brice, West Virginia, 42 miles distant. The second named company entered the field in the spring of 1899, and ships entirely by tank cars, not having a line leading from the field. At the height of the production the company shipped 1,500 barrels daily, but in 1901 this has decreased to 300 barrels. The oil is sent to Toledo where it is refined. The National Pipe Line Company, like the Sun, ships entirely by tank cars, the

oil going to Toledo, Findlay, Newberg and Cleveland. It entered the field in December, 1899, and began shipping the following month. The quantity shipped has ranged from 3,000 to 6,000 barrels per month. In 1899 a small refinery was built at Scio, and is reported to have used about 100 barrels per day. It was short lived, however, for in 1901 the Standard Oil Company secured control of it, and since then it has been quiet.

Geology of the Field.—The surface rocks lie in the Conemaugh formation or Lower Barren Coal Measures, the Upper Freeport coal passing below drainage a few miles to the west, while the Pittsburg coal appears in the hill tops a short distance beyond the eastern limit of the pool. Conotton Creek, flowing in a northwesterly direction and having a broad valley, divides the field into two nearly equal parts. Through this valley the two railroads run and the village is built on it. The topography of the field is rough. The succession of strata below drainage is shown by the following record:

Donaldson well No. 2. Data by J. R. Stevenson:

	Thickness of formation. Feet.	Total depth. Feet.
Conductor	40	40
Soapstone and slate.....	30	70
Limestone and slate.....	70	140
<i>Cow Run sand</i>	25	165
Slate and shells.....	20	185
Coal	5	190
Slate and shells.....	15	205
Coal	3	208
Slate and shells.....	27	235
Slate	10	245
"Hurry Up" sand.....	25	270
Slate	35	305
Coal	7	322
Slate and shells.....	73	385
Gas sand.....	50	435
Coal	2	437
Slate and shells.....	45	485
Sand	15	500
Slate and shells.....	55	555
<i>Salt sand</i>	45	600
Slate and shells.....	100	700
<i>Big Injun sand</i>	95	795
Slate and lime shells.....	362	1,157
<i>Berea sand</i>	33	1,190

The coal seam reported at a depth of 185 feet is probably the Upper Freeport. The sand rock lying 20 feet higher cannot be the Cow Run as named by the driller since the interval between the two should be about 100 feet. The Salt sand ranges in thickness from 40 to 75 feet, and usually contains a large quantity of brackish water, but is sometimes dry.

Below this formation is a bed of dark colored slate, having a thickness of from 15 to 25 feet, and this is succeeded in turn by the Big Injun, consisting of a series of alternating sand and slate layers, and having a thickness usually of less than 100 feet. At times it is charged with brine, but at other times is quite dry. The Berea has an average thickness of between 40 and 50 feet. The upper part of the formation changes gradually into shale, and so it is not sharply delineated. An average section of the formation in this field according to Prof. Beale is as follows:

	Feet.
Gray shelly sand.....	13-15
Like the above, but more compact and shelly.....	10
Pay-rock, fine even grained sand.....	6-11
Dark shale	1-20
Lower part of sand; called "Clover-leaf" by the drillers	3

The upper two divisions are known as "the lime" among the drillers. They are, however, a shelly sand rock containing some carbonate of lime. Thus far but little drilling has been done below the pay-rock, and hence the two lowest strata are not well known. It does not seem probable, however, that the "Clover leaf" sand extends over a considerable area. The most remarkable character of the sand is its absence of dry streaks. It is said that not a dry hole was drilled in the whole field. Of course in the village where a well was driven on nearly every lot, the sand was soon exhausted of oil, so that the later wells were unproductive.

The wells have not been large when compared with some found in other parts of the state. The best did not exceed 125 barrels per day. The production, however, keeps up well, and this, with the absence of dry holes, has made the field a very profitable one. The oil has a gravity of 42 degrees B., a red-brown color, and commands the Pennsylvania price. Usually the flow of gas from the wells has not been large, in fact the quantity has been scarcely sufficient for fuel to operate the wells, but on the west side of the extreme northern part of the field in sections 3 and 9, a few good gas wells have been secured. The rock pressure has reached 400 pounds, and in 1901 the fuel was supplying 175 families in Scio, the rate being 20 cents net per thousand cubic feet. These wells feed the boilers of the Buckeye Pipe Line, the rate being just half of the above. Salt-water has never been troublesome except on the extreme southern side of the field, where in some places the brine flows from the well.

The oil sand in the valley of Conotton creek dips very gently to the southeast. The much greater quantity of gas in the northern extremity of the field suggests that the dip there may be more pronounced, and the same may also be true of the southern margin which may explain the abundance of salt-water in that part of the territory. No evidence of an anticline was found, but the pool may lie on the eastern slope of a low arch.

Other Wells in North Township.—Outside of the Scio pool a number of wells have been drilled and additional tests were being made during the summer of 1901. One or more dry holes have been drilled in sections 27, 33, 15, 14, 8, 1, 13, 5 and 29.

THE PHILADELPHIA ROAD POOL.

This is a small area lying in the southeastern corner of section 13, and the southwestern of 7. The first well was drilled about 1899, but the quantity of oil secured was small and the well was abandoned. Other wells were drilled late in 1901 and with better results. Some work has been done from time to time since that date, with the result that a small pool has been secured. The wells are all small, and after having been pumped a short time do not produce more than from 2 to 10 barrels each per day. The oil is found in the Berea sand, and the rock is shot with from 60 to 100 quarts of nitro-glycerine. The pool does not promise to become of any considerable importance.

THE PLUMB RUN POOL.

This occupies parts of sections 5, 6, 11 and 12 of Monroe township, and a small strip along the north line of Franklin township. The total area in February, 1903, was little in excess of one square mile.

The first well was drilled on the Isaac Miller farm in June, 1902, and began producing 10 barrels of oil per day. Work has been very active since that date, and the number of wells is now (April, 1903,) about 70. The principal farms are the McDevitt and Copeland. The wells are small, but dry holes are few and consequently the territory is quite profitable. The oil is obtained from the Berea sand.

THE BOWERSTON POOL.

This small pool lies in Monroe township, including parts of sections 1, 2, 3, 7, 8 and 9. It is circular in shape, and is almost surrounded by dry holes, and consequently does not promise to become much larger than it is at present.

The field was opened in the fall of 1899, the first well having been drilled on the Fisher farm. It yielded some gas. Another well was drilled the same fall. This was on the Heavlin farm, and it too produced gas. The first oil well was drilled in the spring of 1900, on the Amos Long farm, and started at 10 barrels per day. From that time until the present work has been in progress. The number of producing wells at present (July, 1901,) is about 125, of which 4 yield gas. The production of the pool at the date specified was about 600 barrels per day. In the fall of 1900 it was 950 barrels, the maximum of the field. The gravity of the oil is 42 degrees B. The Buckeye Pipe Line handles the product. The oil is collected by gravity into tanks, of which there are two, each of

1,200 barrels capacity, and is shipped to Brice, West Virginia, through a 3 inch line, the power being furnished by an engine of approximately 60 horse-power.

Like all other pools in the county the producing sand is the Berea. This has a thickness usually of 25 or more feet. The general relations of the sand are similar to those at Scio; at the top is the so-called "lime" having a thickness usually of from 6 to 10 feet; below this is the pay-rock having a thickness of from 6 to 14 feet. On the northwest side of the field gas is plentiful, but farther east and south the quantity is not sufficient to operate the wells. The highest pressure reported is 250 pounds per square inch. Salt-water is abundant on the southeast side of the field, it being estimated that at least 20 barrels are pumped to one of oil. The largest wells in the field started at 100 barrels per day, and those having an initial production of from 30 to 40 have not been uncommon.

The surface rocks lie principally in the Conemaugh formation or Lower Barren Measures, the Upper Freeport coal lying above drainage along the western margin of the field. The interval between this coal and the Berea sand is about 1,010 feet.

Other Wells in Monroe Township.—On the A. Wyant farm in the eastern half of section 33 a dry hole was drilled in 1894 to a depth of 3,950 feet. It was the intention to go to a depth of 4,400 feet, but the tools were lost and the well abandoned. The Berea was found at 1,085 feet. Three other dry holes have been drilled on the same section, one on the Grumble and two on the B. Wyant farms; a dry hole on the Brown farm near the south line of section 3; two dry holes on the northwest corner of section 9; two dry holes in the north half of section 26 on the Heller farm; a dry hole on the southeast corner of section 14; a dry hole on the Birney farm near the middle of section 31; three holes in section 1, one in the northeast quarter, one in the southeast quarter, both dry, and one making a showing of oil in the southwest quarter; on the southeast quarter of section 7 a well making a show of oil has been drilled on the Parker farm, and a second well was being drilled on the same farm in August, 1901; on the Long farm in the southeast quarter of section 13 a well making a showing of oil has been drilled, and another one was being drilled in the summer of 1901; on the Albaugh farm in the northeast quarter of section 30 a dry hole has been drilled; on the Betts farm in the southwest quarter of section 24, a dry hole has been drilled; on the Spray farm near the dividing line of sections 29 and 35 a dry hole has been drilled. It is understood that in all these wells except the first one, the objective sand was the Berea, and doubtless this was found in nearly every case.

OTHER DEEP WELLS IN THE COUNTY.

While depths cannot be given for the following wells, it may be taken with considerable certainty that they reached the Berea sand. The wells are enumerated here to show to what extent the county has been tested.

German Township.—A dry hole on the Lauther farm in the southwest corner of section 29; a dry hole on the Ralston farm in the southwest corner of section 18; a dry hole on the Johnson farm in the southeast corner of section 25; three dry holes near New Jefferson in section 26.

Rumley Township. — A number of dry holes have been drilled in this township just beyond the eastern margin of the Scio pool. These are located chiefly in sections 20, 13, 18 and 17. Besides these the following have been drilled: A dry hole in the southwest quarter of section 12; a dry hole on the Crabb farm near the south line of section 31; a dry hole on the Kimmell farm in the southeast quarter of section 7.

Stock Township.—A well making a showing of oil on the Henderson farm in the southwest corner of section 29; a dry hole on the McComis farm in the southeast quarter of section 34. This well is reported to have gone 700 feet below the Berea in search of the Gordon sand, but without success; a dry hole on the Lacey farm near the center of section 8; a dry hole on the Christy farm in the northwest quarter of section 14.

Franklin Township.—A dry hole on the Pittis farm in the northeast quarter of section 33; a dry hole in section 25 just south of the village Deersville.

Archer Township.—In June, 1901, a well was drilled on the Adams farm in the southwest corner of section 21. The Berea was found having a thickness of 45 feet, with from 7 to 8 feet of pay-rock at the bottom. The well began producing 10 barrels of oil per day. On July 23, 1901, a well was completed on the Welch farm adjoining the Adams, but the results were not as favorable as those in the Adams well. A dry hole was drilled on the Barger farm in the northeast quarter of section 20 in 1899, but a show only of oil was secured; a dry hole on the Strasbaugh farm in the northwest quarter of section 3; a dry hole on the Adams farm on the south side of section 15; a dry hole on the Hoover farm in the southeast corner of section 4; a dry hole on the Pittinger farm in the southwest corner of section 5; a dry hole on the Anderson farm in the southwest corner of section 23.

Cadiz Township.—A large number of failures are recorded in this township. Those outside of the Cadiz pool are the following: Two on the south half of section 33; one in the southwest corner of section 34; one near the middle and one in the northwest corner of section 35; one in the northwest corner of section 2; one in the southeast corner of section 6; one in the eastern part of section 10; one in the northeast corner of section 18; one near the center of section 22; one in the southwest corner of sec-

tion 26; two in the northwest corner of section 27; one in the southwest and one in the northwest corner of section 29; one near the middle of section 33.

Athens Township.—But three deep wells were reported in this township in 1901; in 1895-6 a well making a show of oil was drilled on the McFarland land in section 36; a dry hole was drilled later near the middle of section 11 on the Birney land, and one on the southwest corner of section 18 on the Johnson farm.

Moorefield Township.—Two deep wells, both of which were failures, are reported in this township, one on the Lantz farm in the southwest corner of section 24, and one on the Corban land in the northeast corner of section 34.

Nottingham Township.—Two deep wells, both failures, are reported in this township; one in the northeast quarter of section 6 on the Milliken farm, and one in the southeast corner of section 15 on the Cope tract.

Freeport Township.—Three tests have been made here, but all have been failures. One is in the southeast corner of section 10, another in section 18 near the village of Freeport, and the third in the southeast quarter of section 30.

Washington Township.—But two deep wells are reported in this township; a dry hole on the House estate in the southwest corner of section 10, and one on the Willison farm in the northwest quarter of section 21.

JEFFERSON COUNTY.

The search for oil and gas in this county has been persistent and extensive. The discovery of important reservoirs of natural gas in the adjacent part of Pennsylvania naturally stimulated the enterprising citizens of the Ohio Valley to test the rocks in their vicinity. Every township has had at least one deep well drilled in it, and in several they may be counted by the dozen. Several small reservoirs of oil and gas have been found, but the results have not been commensurate with the money expended. The surface formations lie almost if not entirely in the Cone-maugh formation or Lower Barren and the Monongahela formation or the Upper Productive Coal Measures. The topography like that of the counties to the south and west, already discussed, is very rough. The productive sand is in all cases the Berea, which everywhere underlies the county, and which has been proven to be the lowest formation from which either oil or gas in commercial quantities can be expected. The principal pools or reservoirs are as follows:

1. The Gould Oil Field.
2. The Island Creek Oil Field.
3. The Toronto Gas Field.
4. The Port Homer Oil Field.
5. The Knoxville Oil and Gas Field.

THE GOULD OIL FIELD.

This comprises less than one square mile, and occupies part of sections 2, 3, 8 and 9 of Cross Creek township. It is situated three miles west of Mingo, and is traversed by the Pennsylvania railroad.

The pool was discovered in 1895, the first well having started at 125 barrels per day, but the decline of this was so rapid that the well was abandoned in one year. The second well, which was drilled a short time afterwards, started at only 10 barrels per day, but was still producing in 1901. Work was pushed with energy and by 1898 the drilling had been done. It is stated that no wells have been drilled in the field since that time. Of the 60 wells drilled, at least 25 had been abandoned by August, 1901.

On the extreme western edge of the pool several gas wells have been secured, and the product of these was used to operate the territory. Generally the gas produced by the oil wells was small, so that the greater number had to be pumped from the start. It is claimed that at one time the field produced 1,200 barrels per day, but by the summer of 1901 this had dropped to 200 barrels or less per week. The oil has a bright red color and commands the Pennsylvania price. Salt-water is abundant, but is much less so on the northwest side of the field than it is on the southeast. The wells were shot at first with from 30 to 200 quarts of nitroglycerine, and many have been shot a second time, this charge being as a rule smaller than the first one. The Berea is found in the valley at about 1,200 feet, and has an average thickness of perhaps 33 feet. From what has been said of the number of abandoned wells, it is clear that the sand is quickly exhausted, and the field must necessarily soon become a thing of the past.

As might be expected a number of wells have been drilled along the eastern edge of this township in the valley of the Ohio river. Four or five have been sunk within the city limits of Steubenville alone, but the results have fallen far short of the expectations of the operators. Three of the wells produced gas, but in small quantity, and all but one have been abandoned; the latter well supplies gas for one family only. These wells reached the Berea at about 1,250 feet, but the sand was thin and unimportant.¹ Two wells, both dry, have been drilled in or near the limits of Mingo. In the southeastern corner of the township in section 25, a dry hole has been drilled. Southwest of the Gould field a number of wells have been sunk in sections 7, 13, 14 and 19. These have been failures, but have made sufficient showing of oil to induce further exploration.

THE ISLAND CREEK FIELD.

This lies in sections 5, 11, 16, 17 and 22 of Island Creek township, has a length of about 3 miles and a maximum width of less than one-quarter of a mile.

¹*Geol. Sur. of Ohio*, Vol. VI, p. 336.

The pool was opened in the fall of 1889, the first well having been drilled on the farm of James Blackburn. The Berea was found at a depth approximating 1,000 feet, and a 30-barrel well was secured. This is still producing, but not more than one barrel per day. Drilling has been in progress irregularly since that time, and by August, 1901, forty-five wells, of which seven only were dry, had been completed. The wells were small, the greater number starting at from 8 to 10 barrels. The pressure of gas has been light, so that many wells have had to be pumped from the start. Considerable salt-water is found, but the field is quite spotted in this respect.

The following record of McKeown well No. 2, on the Morrow farm, shows the stratigraphical succession:

	Thickness of formation. Feet.	Total depth. Feet.
Conductor	20	20
Slate	20	40
Limestone and shells	20	60
Sand	14	74
Slate	101	175
Sand	25	200
Slate	150	350
Sand	40	390
Slate	180	570
Sand	70	640
Slate	95	735
Sand	132	867
Slate	295	1,162
Shelly slate	10	1,172
Black slate	40	1,212
<i>Berea sand</i>	29	1,241

The sand struck at 570 feet is the Salt sand, and that passed through at 867 marks the base of the Big Injun. While the wells in the pool have all been small they are nevertheless valuable, since they are long-lived. As late as August 1, 1901, two wells only had been abandoned.

THE TORONTO GAS FIELD.

This lies near the village of Toronto, in the northeast corner of Island Creek township, and is restricted almost wholly to section 36.

The wells, 12 in number, are reported to have been drilled in the years 1891-2. Of these 3 were failures, and of the others 6 were still producing in 1901. The closed pressure was originally 325 pounds per square inch. A feature of the field is the absence of salt-water, the wells not requiring packing. Originally the wells were owned by the Toronto Oil and Gas Company, but they have passed into the control of the Tri-State Oil and Gas Company. The gas is piped to Toronto, where a rate of 22½ cents net per thousand cubic feet is charged.

Outside of the two fields mentioned a number of wells have been drilled in this township: One dry hole on the Robertson farm in the eastern half of section 7; a dry hole on the Dobbs farm in the southwestern quarter of section 33; a dry hole on the Walker farm near the west line of section 10; a dry hole on the Finley farm in the northwest quarter of section 34, and one on the Powell farm in the northeast quarter of the same section; in the northeast quarter of section 5 three wells, two of which were dry and the third a small producer, now abandoned; two dry holes in the southwest corner of section 12. It is safe to say that all these wells extended to the Berea sand.

THE PORT HOMER OIL FIELD.

This is a very small pool occupying parts of sections 5 and 6 of Saline township. The first well was drilled in the winter of 1899-1900, but was very small, making a barrel or two only per day. The Berea grit is said to have been struck at a depth of 715 feet. In the spring of 1900 the second well was completed and started at 100 barrels per day, but this rate was not long maintained. Work has been progressing since that time and about 20 wells have been drilled, but more than one-third of these were dry. The Berea is found along the river front at depths ranging from 600 to 620 feet, but on the opposite side of the river the same formation is reported at 598 feet. However, the surface there is lower. The relations, nevertheless, strongly suggest a low arch with the Port Homer wells on the western slope.

A number of deep wells have been drilled in other parts of the township: Two dry holes near the river in the extreme southeastern part of the township; a dry hole in the southeast corner of section 5; a dry hole on the McCullough farm near the west line of section 7; a dry hole near the mouth of Yellow Creek in section 8; two dry holes, one on the Mills and the other on the Gray farm, in the southwest corner of section 11; three wells on the Taylor farm in the southeast quarter of section 17, two of which produced some oil, while the third was dry; a dry hole on the Burnett estate near the south line of section 18; a small producer, now abandoned, on Yellow Creek along the eastern line of section 13, and a dry hole near the middle of the same section; two small oil wells and one dry hole on the Leatherberry farm in section 23; a dry hole in the village of Irondale. In all these wells the objective plane is the Berea grit, and it is not improbable that every well reached that horizon.

THE KNOXVILLE OIL AND GAS FIELD.

This is a small area lying on the east and west sides of the village of Knoxville, in Knox township. The producing territory lies in sections 14, 15, 20 and 21, but does not embrace over one-half of a square mile. The first well, which was drilled in 1896, started at two barrels only per

day, but the next well began producing 27 barrels, and is the largest producer in the field. Nearly all of the 17 oil wells were drilled in 1896. They lie west of the village, while the gas wells lie to the east. The gas wells, four in number, were drilled within the past two years. Their closed pressure is reported at 325 pounds per square inch. They are owned by the Tri-State Gas and Oil Company, but have not been used as yet. Mr. J. J. Crawford, who is well informed concerning the field, reports that the oil wells lie on the western slope of an anticline and the gas wells on the summit. Both products are derived from the Berea grit, which has a thickness of about 50 feet, and is quite constant in character. The sand is fairly dry, and but little water is found in the Salt sand.

A large number of wells has been drilled in other parts of the township: A dry hole on the river bank in the northeast corner of the township; three small gas wells in or near the village of Empire; a dry hole on the Sapp farm in the southwest corner of section 33; a small gas well on the river bank near Calumet P. O.; a dry hole in the village of Toronto; a small gas well on the Gaston farm in the southeast corner of section 31; a dry hole on the Wasson farm in the southwest corner of section 1; a dry hole on the Snyder farm in the southeast corner of section 2; a dry hole on the Fitzpatrick farm in the northeast corner of section 3; two dry holes on the Taggart farm in the northeast corner of section 4; two dry holes on the western half of section 10, one on the McGhie, and the other on the Runyon farm; two oil wells and three dry holes in the northeast corner of section 16; a dry hole on the Cooper farm in the northeast corner of section 15; 2 dry holes on the southern half of section 14, one on the Mills and the other on the Andrews farm; one oil well and 3 dry holes in the northwest quarter of section 13; a dry hole on the Swickard farm in the southwest corner of section 20; 4 small oil wells and 2 dry holes in the eastern half of section 26. It may be taken with almost certainty that these wells reached the Berea grit.

OTHER DEEP WELLS IN JEFFERSON COUNTY.

Brush Creek Township.—A well was drilled on the Hickman farm in the northeast quarter of section 2 in the fall of 1900, but was dry. In the summer of 1900 a deep well was drilled on the McBane farm in the southeast quarter of section 15. It made a show of gas, but no oil. Several years ago a Berea well, which was dry, was drilled on the Dorrance farm in the southeast quarter of section 32. More recently a small oil well was drilled on the Moore farm in the southwest quarter of section 31.

Ross Township.—A number of deep wells have been drilled in this township, some of them, according to report, many years ago. It is not improbable that the earliest of these went no deeper than the Salt sand. On the E. George farm in the southwest corner of section 23 three wells have been sunk; of these two were dry, but the third yielded some oil, though

it is now abandoned. On the A. George farm in the northeast quarter of section 28 the same number of wells has been drilled with results similar to those previously reported. Two dry holes have been drilled on the McLain farm in the northern part of section 6. All the wells reported are along Yellow creek. In early times the brine from the wells was used for the manufacture of salt. It is said that oil in commercial quantities was not found in the Berea, but that it was occasionally found in the Big Injun. A small quantity of oil is reported to have been hauled away from this valley between 1860 and 1870.

Springfield Township.—A dry hole was drilled on the Dorrance farm in section 4 near the village of Bergholz, and one on the Calhoun farm in the southeast quarter of section 8.

Salem Township.—A dry hole has been drilled on the Graham farm in the southwest quarter of section 23, and one on the Kirk farm in the northeast quarter of section 22.

Wayne Township.—A Berea well was drilled on the Reed farm in the northwest quarter of section 23 in 1899. The sand was found at a depth of 1,200 feet, and has a thickness of 41 feet. The well made a show of oil and considerable gas. Another Berea well was drilled on the Blackburn farm in the same section. It made nothing better than a show of oil. Other dry holes have been drilled as follows: One on the Hervey farm in the northwest quarter of section 28; one on the O'Brien farm in the southeast quarter of section 24; one on the Starr farm in the northwest quarter of section 18; two in section 17, one each on the Maxwell farm in the northwest quarter, and the Simeral farm in the southeast quarter; one on the Miser farm in the southwest quarter of section 12.

Smithfield Township.—Two Berea wells, both dry, have been drilled on the J. M. Galbraith farm in section 11. The first one was drilled about 1895 and made a show of oil. Its depth was approximately 1,560 feet. The second well was drilled in 1900 and had a depth of over 1,600 feet. In section 10 four wells have been drilled, all in 1900, and the fifth well was being drilled in the summer of 1901. One of these wells produced 25 barrels of oil per day when first drilled, and in July, 1901, was producing between 6 and 10 barrels in the same length of time. The other wells were dry. On the Runyon farm in section 17 a Berea well was drilled in 1896.

The log of this well is as follows:

	Thickness of formation. Feet.	Total depth. Feet.
Conductor	15	15
Coal (<i>Pittsburg</i>)	6	21
Shale	19	40
Buff colored rock	80	120
White shale	160	280
Black sand	25	305

	Thickness of formation. Feet.	Total depth. Feet.
White shale	10	315
"Hurry-up" sand	60	375
Black shale	10	385
Bastard limestone	10	395
First Cow Run sand	50	445
White shale	60	505
Second Cow Run sand	25	530
White shale	65	595
Black shale	50	645
Coal	9	654
Black shale	20	674
First salt sand	80	754
Black shale	110	864
Second salt sand	55	919
<i>Big Injun sand</i>	250	1,169
Slate	25	1,194
"Squaw" sand	20	1,214
Slate and shale	358	1,572
<i>Berea sand</i>	35	1,607

It is seen from this record that the interval between the Pittsburg coal and the Berea grit is 1,551 feet. The Cow Run sands, so-called, are out of place. Instead of an interval of 400 feet between the two, the interval here given is only 60 feet. As has already been stated in this report, no reliance can be placed on the drillers identification of this sand. The great thickness of the coal seam found at 645 feet should be taken with much allowance.

On the Kithcart farm in section 15 a dry Berea well was drilled in 1896; a dry well has been drilled near Adena in section 32; on the Sutherland farm in section 28 two wells, both dry, have been drilled; two wells, both dry, have been drilled in section 29, one on the Thompson and the other on the Henry farm; on the J. B. Smith farm in section 30 a dry hole was drilled several years ago; on the Wm. B. Scott farm in section 5 the Berea was found at about 1,700 feet, but was dry; in section 6 two Berea wells have been drilled, one on the Sutherland and the other on the Cope farm, and both were dry; near the eastern margin of section 14 two dry holes have been drilled, and one near the western margin of section 8. It is thus seen that of the 20 Berea wells drilled in this township, one only is a producer.

Mt. Pleasant Township.—Three dry holes have been drilled in this township, one in the southwest quarter of section 4, one in the northeast quarter of section 18, and one in the northwest quarter of section 29.

Wells Township.—Several Berea wells have been drilled in this township: A dry hole on land belonging to the bank of Smithfield in the southeast quarter of section 21; a dry hole in the northeast quarter of section 28; a dry hole on the Puntney farm in the southwest quarter of section 18;

a dry hole in the southwest quarter of section 35; a dry hole on the Hundman farm in the northeast quarter of section 12; a dry hole on the Ekey farm in the southeast quarter of section 11. Several wells have been drilled at Brilliant on the river bank. One of these produced gas, which was used in a rolling mill. The well is said to have been ruined by the flood of 1884. The interval between the Pittsburg coal and the Berea sand in this locality is reported at 1,560 feet.

Warren Township.—One dry hole has been reported from this township. This was drilled many years ago near the village of Portland.

COLUMBIANA COUNTY.

The surface rocks in this county lie in the Allegheny formation or Lower Productive and the Conemaugh formation or Lower Barren Coal Measures. The eastern and southern parts are hilly, the highest points rising more than 500 feet above the valley of the Ohio river. The strata dip rapidly to the south: thus at Wellsville the Berea is found at a depth approximating 550 feet below the river valley, while at Steubenville the same formation is found at about 1,200 feet. The distance between the two places is about 20 miles. From this county north the Berea ceases to be a deep formation, meaning by this that the sand rarely attains a depth of 800 feet, even in the south, and in many cases is much less than this.

A very large amount of drilling has been done in this county and much of it dates back to an early day. The city of East Liverpool, in the southeast corner of the county, must be regarded as one of the pioneer natural gas places in this country. The first well is reported to have been drilled in 1859,¹ and to have found gas at a depth of 450 feet. Whether this well resulted from Drake's discovery in Pennsylvania, or whether from a search for brine for the salt works, does not appear certain. It is claimed that after this well was finished a committee went to Fredonia, New York, to ascertain what use was there made of the gas and how it was controlled.

Mr. H. R. Hill reports having found a deep well drilled at this place on his return from the army in 1865. It was sunk for oil, but was unsuccessful in this respect. However, it did yield gas, though this was regarded worthless. Mr. Hill secured control of this product, and used it in two residences and a pottery. Later he drilled another well near this one, securing so strong a flow of gas that the well was known as the "Bonanza." Among other purposes this gas was used for lighting the streets. Several additional wells were drilled in the same vicinity, and then Mr. Hill sold out to the Bridgewater Gas Company. From the period of these early wells drilling has been done from time to time in this vicinity until 1900, when two wells were sunk in the Ohio valley. The prime object of nearly all this work was to secure gas for the potteries, but the effort has been unsuccessful. The production has been small and the

¹*Encyclopædia Brit.*, Ninth Ed., Vol. X, p. 88.

wells short-lived. According to Dr. Orton, gas was first used for lighting the streets and for domestic purposes in a general way in 1874. The number of families supplied at that time was between 50 and 60, the charge being from \$2.00 to \$2.50 per month for each fire.

The gas is derived from the Berea sand, which has a thickness ranging from 60 to 120 feet. It is worthy of note that as this formation rises nearer the surface its thickness increases. Concerning the structure of the field Dr. Orton says:¹

"East Liverpool lies in whole or in part, upon a low fold in the strata which is probably an extension of the Fredericktown anticlinal of Prof. I. C. White. The reality of the fold is made apparent from the fact that the Berea grit descends in both directions from Liverpool. At Dry run, four miles east, it lies about 100 feet lower than it does at Liverpool. At Wellsville, four miles west, it lies seventy feet below the Liverpool level, as has been demonstrated by the drilling of a number of wells at this point."

In the search for oil and gas, work has not stopped with the Berea. In the Knowles well a depth of about 2,500 feet below this was reached. Beneath the Berea two sand formations were found, one at a depth of 964 and having a thickness of 41 feet, and the other at 1,800 and having a thickness of 5 feet. The higher of these two sands is reported to resemble closely the Berea, and also to produce gas. The lower of the two contained a small quantity of both oil and gas. The result of this well, however, was far from satisfactory, and it came to be recognized that when the Berea sand was passed and was found dry that the last hope of gas or oil was gone. It is worthy of note that this deep well did not reach the base of the Ohio shale formation.

Yellow Creek Township.—A well is reported to have been drilled in the valley of Yellow creek in 1865, and to have begun producing 100 barrels of oil per day, the pay-rock having been struck at a depth of 540 feet. Two additional wells are said to have been drilled about the same time in that vicinity, but the results must have been unsatisfactory, for with them work ceased for nearly 25 years. Late in the eighties a Wellsville company interested in the iron business drilled a well to the depth of 3,250 feet on the Hibbits farm in search for gas for its mills. A small flow was secured in the Berea, but the great shale series below was barren, so that the well was a failure. In 1899 the Wellsville oil field was discovered, the first producer having been drilled on the James Wells farm, just north of the town. The well started at 15 barrels per day, and drilling has been done at irregular periods from that day to the present time. Nearly 20 oil wells have been secured. These have, in the main, been drilled close together, and so occupy a very small area. The wells have started as high as 200 barrels per day, but the decline has been rapid. In August, 1901, the pool

¹*Geol. Sur. of Ohio*, Vol. VI, p. 335.

was producing about 500 barrels of oil per month. About one mile northeast of this field several gas wells have recently been drilled on the Bane, Adams and Stroup farms. In the summer of 1901 no use had been made of them, but it was the intention at that time to pipe their production to Wellsville. The rock pressure of these wells was reported at 350 pounds. The oil and gas in the Wellsville field are derived from the Berea grit, which is uniform in character and has a thickness of about 45 feet. This formation is quite dry, but there is considerable brine in the Salt sand.

Deep wells have been drilled in other parts of the township as follows: A small well on the Johnson farm two miles north of Wellsville; a dry hole on the Kerr farm one-half mile west of the Johnson well; a dry hole on the A. R. Smith farm near the middle of the north side of the township; a dry hole on the Wm. McBane farm in the northwest corner of the township; a small well on McQueens run near the lower end of Wellsville; a dry hole on the Boyd farm near the middle of the township; a dry hole on the Runyan farm near the southeast corner of the township; a dry hole on the Hammond farm about one mile west of Wellsville; a dry hole on the James McBane farm in the southwest quarter of the township.

Madison Township.—At and in the vicinity of Williamsport in this township and in corners of the adjacent townships of St. Clair and Elk Run a number of deep wells have been drilled within the last 40 years. For information concerning this territory the Survey is indebted to Mr. W. H. Crawford, who has been in the field during the long period mentioned. In 1860 or 1861 Mathers and Hanna, of New Lisbon, drilled a well on the W. H. Crawford farm, striking the Berea sand at 550 feet. This yielded a little gas but no oil. It is claimed that this well was begun with the old-fashioned spring-pole, that the middle portion was drilled with horsepower, and that it was finished with steam. At or about the same time that this well was being drilled another one was being sunk by water power on what is at present known as the Cliff farm. A little later a well, located by a "smeller," was drilled on the same tract and gas pressure sufficient to blow the tools from the well was secured. The people, however, were afraid of the well, and hence it was abandoned. The next well was located by an oil "smeller," the Rev. Patterson, of Darlington, Pennsylvania, on the Conkle farm in the northwest corner of St. Clair township. The Berea sand, having a thickness of 70 feet, produced a heavy oil suitable for lubricating purposes, and it is said that over 1,000 barrels were hauled away. In 1865 a well was drilled on the James Crawford farm, in Elk Run township, and a strong flow of gas was found in the Berea. This, however, was regarded as worthless and the well was abandoned. The same year a well was begun on the Russell farm, in Madison township, but at a depth of 420 feet was abandoned. The driller declared that there was no use going deeper when the sand was too fine to contain water.

From that time until 1887 the field was quiet. In the latter year three wells were drilled in the vicinity of Williamsport. One of these was located on the W. H. Crawford farm in the northwest corner of St. Clair township. In this the Berea was found at a depth of 650 feet and produced a small quantity of gas. Work continued until a depth of 1,600 was attained, but neither oil nor gas was secured. The second well, drilled on the Alum Cliff farm, attained a depth of 930 feet, and made a little oil and considerable gas. The latter supplied two residences during the ensuing 12 years. The third well was drilled on land of James Robinson, in Madison township, and the Berea yielding nothing more than a small quantity of gas, the drill was kept at work until a depth approximating 3,000 feet was reached. About 250 feet below the Berea a stratum of soft sandstone three and one-half feet in thickness was found, but it yielded nothing, and the well was of no service beyond showing that when once the Berea sand has been passed all hope of securing oil or gas must be abandoned in this part of the state.

No further work was done in the territory until 1897, when a well was drilled on the old Conkle farm, now owned by John Davis. It made a show only of oil. A well was drilled in the same year on the Alum Cliff farm, the result being a gas pressure of 170 pounds per square inch. Later it began yielding a small flow of oil and in 1901 was still producing. Other wells were drilled in the same territory that year and further testing has been done from time to time until the fall of 1900. During the three years preceding the latter date 22 wells had been drilled in the field. In August, 1901, there were 5 producing oil wells, the largest making 3 barrels only per day. The oil has a gravity of 33 deg. B., and is used as a lubricator. When the gas production was at its height the Alum Cliff Gas Company piped the product to East Liverpool. The output of the wells, however, speedily declined, and in 1900 the line was removed. In the summer of 1901 the wells supplied 11 families, but the yield more than met this demand.

The Berea sand has a thickness of 70 feet in this territory. The gas is usually found at a depth of about 50 feet and the oil near the base of the formation. The sand is fine and hard except where the oil is present. But little salt-water is found in it.

Outside of this field a number of deep wells have been drilled in Madison township: On the J. Crawford farm in the southeast corner of section 11 two Berea wells have been drilled; of these one was dry and the other made a little oil; on the neighboring farm owned by S. McGurdy a well was drilled within the past two years; a well is reported to have been drilled at the village of West Point many years ago, and to have produced a small amount of heavy oil which the farmers used as a lubricator; a few years ago a well was drilled on the farm of J. McCready in section 32, but made nothing more than a small showing of gas.

St. Clair Township.—Beside the wells already mentioned as forming part of the Williamsport field the following have been drilled in the township: On the Moore farm in the northwest quarter of section 17 a Berea well producing some gas, about the year 1900; on the Rayl farm in the northeast quarter of section 19 a Berea well having a closed gas pressure of 125 pounds per square inch; a Berea well yielding some gas on the McDonald farm in the northwest quarter of section 30; a well making some gas on the T. W. Huston farm in the southwest corner of section 21; a number of producing wells along the Middle Fork of Beaver creek in the eastern part of the township from Fredericktown south. Drilling is said to have been begun in the latter locality many years ago. The production is derived from the Berea sand.

Elk Run Township.—A well is reported to have been drilled on the Cope farm in the southeast quarter of section 24, before the civil war. Formerly it yielded much gas and is said to be used in the farm residence at the present time. Many years ago a well making considerable gas was drilled on the Thompson farm, near Elkton. This encouraged further exploration and three wells have since been drilled, all of which were failures. About the year 1898 a Berea well was drilled on the Wilson farm in the southeast quarter of section 25. The sand was reported nearly 100 feet thick, and so charged with salt-water that the latter rose rapidly to the top of the well.

Center Township.—Wells have been drilled in the vicinity of Lisbon at various periods during the past 40 years. The earliest of these were in search of oil, and were put down not many years after Drake's discovery in Pennsylvania. All were financial failures. They disclosed, however, large quantities of salt-water and some gas, and resulted in the establishment of salt works, the gas having been used as fuel. These works have long been abandoned. The modern work in the search for oil and gas in this vicinity began about 1884, when a well was drilled just south of Lisbon to a depth approximating 1,600 feet. The well yielded a small quantity of both oil and gas, but not enough of either to warrant operating, and so was abandoned. In 1886 a well was drilled on the Valker tract along the Lisbon corporation line. Work did not cease until the drill had passed 972 feet below the Berea.¹ A sand rock having a thickness of 12 feet is reported to have been found 450 feet below the Berea, though it is not given in the record to which reference has just been made. The Berea yielded some gas, which was used in the city mains, but salt-water soon ruined the well. Three additional wells were soon drilled in the same vicinity, one reaching a depth of 1,100 feet, but the remaining two stopped with the Berea. Of these one was dry but the others yielded some gas, one of which is still producing. About the same time a well was drilled at the United States Tile Works. It made some gas but was soon ruined

¹*Geol. Sur. of Ohio*, Vol. VI, p. 322.

by salt-water. Three additional wells were drilled in the vicinity of Lisbon late in the eighties, but without satisfactory results.

No further exploration was done in this part of the county until 1899, when two Berea wells were drilled within the Lisbon corporation. Both were failures. In the same year a Berea well was drilled on the Harbaugh farm, one-half mile southwest of town, but this well also was a failure. About the same time a well was drilled one mile southwest of Lisbon on the old Philpot farm. A shallow sand, found at a depth of about 375 feet, made a good show of gas, and the Berea yielded gas, oil and brine, but the well was abandoned. In the winter of 1900-01 work was begun on the Fink farm along the line separating sections 32 and 33, and since that period three additional wells have been drilled. All reached the Berea, and 3 produce gas, the rock pressure of which was between 250 and 300 pounds per square inch. No use was being made of this as late as August, 1901, but the owners of the wells expected to pipe the production to Lisbon. The Berea grit in the vicinity of Lisbon has an average thickness approximating 50 feet. The sand contains much salt-water, thus greatly damaging the territory.

Unity Township.—A deep well is reported to have been drilled on the old Mendenhall farm, about one mile east of New Waterford, somewhere between 1860-70. It is reported to have yielded a small quantity of heavy oil and much salt-water, the latter supplying the salt works for a short time. The well has long been abandoned. About the year 1889 a well having a depth approximating 800 feet was drilled in the village of New Waterford, and after having been shot produced a small quantity of oil. It was pumped a short time and then abandoned. This well encouraged further explorations, and one located on the Thompson farm one-fourth of a mile east of the village was soon begun. At about 600 feet some gas was found, and at 1,200 feet a show of oil. Work did not cease until a depth of 1,700 feet was reached, but nothing was found to repay the operator for his heavy expense. No further work was done until 1897, when a well was drilled on the land of Ephraim Ruperts, adjoining the Thompson farm. A good show of gas was found in the Berea at a depth between 600 and 700 feet, but a heavy flow of brine was encountered below the pay-rock, and this ruined the well. Another one was then drilled on the Thompson place and the gas secured in the Berea was piped to New Waterford, but brine soon overcame the gas. Eight additional wells have since been drilled near the village, the last one in 1899. Nearly all made some gas, and the results simply duplicate those already given. They supply the village with light and fuel, the rate being 25 cents per thousand cubic feet, with 2 per cent. off for cash. Salt-water is the great enemy of the field. It lies below the pay-rock, from which it is separated by a hard stratum. When the latter is penetrated the brine rises and drowns the gas. The productive strip has a length of one mile and a width of perhaps one-eighth of a mile.

On the Flowers farm, near East Palestine, along the east side of the township, a well was drilled about 1890, and is reported to have gone to a depth of between 1,700 and 1,800 feet. No data as to the results are at hand, but it is safe to say that the well was a failure.

Middleton Township.—About 1899, a Berea well which was a failure was drilled on the Huston farm in section 34. In 1900 a well was drilled near the village of Mill Rock. The depth has not been learned, but it probably extended to the Berea sand. It made some gas, but the quantity was small, and the well was abandoned.

Fairfield Township.—Two wells were drilled on the Nichols farm, about two miles southwest of Columbiana, in 1900. The Berea was found in normal position and character, but was dry in one well, and made a show only of oil and gas in the other.

Wayne Township.—A well has been drilled on the Rice farm in section 15. No definite data are at hand, but it is known that the well was a failure. There is no reason to doubt that the Berea grit was found.

Knox Township.—Two small pools have been discovered near the village of Homeworth, in this township. One lying northeast of the village was discovered in 1899, the first well having been drilled on the Yaggi farm. The Berea sand was reported at a depth of 618 feet, and was 35 feet thick. The production of oil was small, but the well is still (1901) being pumped. In the same summer a well was drilled on the Cameron farm, one mile southwest of the Yaggi tract, and began producing about 7 barrels per day, a rate that was being maintained in August, 1901. Drilling has been done in the field off and on from the time of the completion of the first producer, and about 30 wells have been sunk, of which one-third were dry. The best wells had an initial production of about 15 barrels per day, but the rate soon decreased to a small fraction of this. The sand contains but little gas, and consequently the wells have to be pumped from the start. The oil commands the Pennsylvania price, and is shipped in tank cars. The Berea sand ranges in thickness from 35 to 52 feet, and is quite hard. Shots of from 60 to 100 quarts are used, and some wells have already received the second charge.

The second pool, near Homeworth, lies southeast of the village, and was discovered in July, 1900. This first well was located on land of the Brooks heirs, and began producing 30 barrels per day. Work has been progressing since that time, and by August, 1901, twenty wells had been drilled. These are larger producers than those in the pool previously described, the best starting at 30 barrels or more per day. But two dry holes have been drilled thus far. The production is derived entirely from the Berea grit, which has a thickness of 50 feet. The pay-rock lies at the bottom of the formation, and is frequently separated from the sand above by a bed of slate from 6 to 8 feet thick. The sand is softer than that in the north pool, and is shot with from 10 to 50 quarts.

Lying east of the village and between the two pools previously noted are several gas wells having a closed pressure of from 200 to 225 pounds per square inch. By far the greater part of the production is piped to Alliance, where it is used in the works of the Morgan Engineering Company. The gas is derived from the Berea sand. Besides these wells a number of dry holes have been drilled, one reaching a depth of 1,400 feet, or about 700 feet below the Berea. Neither oil nor gas was found below the sand just named.

West Township.—A dry hole was drilled on the Simms farm at East Rochester in the winter of 1900-1901. The Berea grit is reported to have been struck at 725 feet, and to be 42 feet thick.

Hanover Township.—In the spring of 1900 a Berea well was drilled two miles east of Hanoverton, but nothing more than a large quantity of salt-water was found. About the same time a Berea well was drilled two miles southeast of Hanoverton, and made a showing of a heavy oil. This was bailed for a short time, but was never pumped.

Washington Township.—A deep well is reported to have been drilled near Salineville in the fall of 1900. The Berea was found at about 800 feet, but hope was not abandoned until a depth approximating 3,200 feet was reached.

PERRY COUNTY.

A large amount of drilling has been done in this county, the objective stratum being in nearly every case the Berea grit. Quite recently a deep well has been drilled to the Clinton sand near Junction City, and the small quantity of oil found was sufficient to encourage another test, which is now in progress. A record of the completed well has been given in the chapter treating of the Central Ohio Natural Gas Fields. Thus far only one field of importance has been discovered in the county, and that is reviewed below.

THE CORNING OIL AND GAS FIELD.

Location and Area.—This field lies in the three counties, Athens, Perry and Morgan. Leaving out of consideration at present a few small outlying pools, and starting at the south, the productive territory may be said to begin in section 22, Trimble township, Athens county. From this point it runs almost due north to the Perry county line. The widest part of this portion of the field does not exceed one-half mile, while the narrowest portion permits of a single row only of wells.

It enters Monroe township, Perry county, in section 33, and runs almost due north towards Corning, but bends to the northeast about one mile south of that place. Here the productive territory attains a maximum width of 3 miles, the greatest in the field. The northeast course is continued to the Morgan county line, where it turns due north, skirting

that line with a productive strip about one-half mile wide for $2\frac{1}{2}$ miles, when it turns slightly to the east, entering Morgan county in section 31 of Deerfield township. From that place it extends through section 30 and into section 19, beyond which oil has not been found. Development of this part of the field is retarded by floods of salt-water, which limit it in this direction. The total length of the field is about 14 miles.

Outside of this belt are four pools, two of which are of little importance. One lies around Glouster, and has an area of less than one square mile. A second one lies in sections 22 and 29, a short distance northwest of Glouster. This is the principal territory from which the gas of Corning and surrounding towns is derived. A third pool lies around Porterville, and the fourth, known as the Oakfield, lies from 3 to 5 miles north of Corning. It includes parts of sections 5, 21, 28, 29, 32 and 33 of Pleasant and 22, 27 and 34 of Bearfield townships. This part of the field was developed in 1900.

Discovery.—Probably the first deep well drilled in the Sunday Creek valley was near Burr Oak, about 4 miles south of Corning. Its date is not now known, but it must have been 40 or more years ago. Its depth is likewise unknown, but it is reported to have penetrated the Salt sand. To this day it flows salt-water, and with it sufficient gas to be ignited. This well, however, seems not to have aroused suspicion that there might be valuable liquids other than salt-water buried in the rocks.

The discovery of oil in the Corning field was a matter of accident, and resulted directly from a scarcity of water for the Toledo and Ohio Central railroad. To remedy this a deep well was drilled in August, 1891, at the round-house, about three-fourths of a mile south of Corning. The only water found was in the Salt sand, which is reported to have been struck at a depth of 630 feet. The supply was copious, but the salinity prevented its being used in locomotives. This brine was shut out of the well by casing and the drill forced down to a depth of 1,507 feet. Finding no water at that depth work ceased, but a few days later oil was thrown to the top of the derrick, and there were smaller eruptions later. However, further disturbances of this sort were prevented by the company closing the well.

Development.—The disclosure made by this well attracted the attention of oil men, who immediately entered the field and began leasing territory. The citizens of Corning feared the land was falling into the hands of the Standard Oil Company, and that it might not under such conditions be developed for years. Accordingly a home company, styled "The Sunday Creek Oil and Gas Company," was organized in February, 1892, to make certain the development of the territory. The capital stock was placed at \$10,000 in shares of \$50, and \$8,900 of the stock was sold. Much of this was raised by citizens of the town subscribing for single shares.

The new company was successful. By January 1st, 1898, 255 per cent. in dividends had actually been paid to the stockholders. In September, 1898, a power for pumping the wells, and costing over \$7,000, was erected, the contractor taking the product of the wells until it paid for the plant. In November, 1899, the property, together with \$1,250—the amount received in excess of the cost of the plant—was turned over to the original holders. On July 1, 1900, the power was pumping 20 wells, which had a daily production of 40 barrels.

The first well drilled by this company was on the William Fisher farm in northwest quarter section 14, Monroe township, Perry county. The Berea was struck at 1,012 feet, but the indications were so unfavorable for a paying well that it was not considered advisable to shoot it. However, on June 2d, 1892, after waiting nearly a month, the well was shot with 80 quarts of nitro-glycerine, which had been hauled from Sistersville, W. Va. The cost of the shot was \$200. The first day following the shooting of the well it produced 12 barrels, and a year later was still producing 10 barrels per day. Following this other wells were drilled in sections 14 and 15. In all 25 have been drilled, only 3 of which were dry holes.

Other companies began work and the territory was rapidly leased and tested. Naturally, operations began near the round-house, where oil had first been shown to exist. From this as a center the drill moved out in all directions until the limits of the field had been disclosed. The later work has been along the northeast end of the territory, in Morgan county, where the oil seems to be shut out by reservoirs of salt-water. During the summer of 1900 the valuable pool in the Oakfield district was developed, though small wells had been found there several years earlier. The principal farms are the Porter, Longstreth, Donnelly, Monahan, McDonald and Grannan. The first well was on the Porter farm and was finished early in 1900. Its production was 35 barrels the first day. The second well was on the Monahan farm. It was completed soon after the Porter well and had an initial flow of 45 barrels in 24 hours. The next two wells were drilled on the Longstreth farm, and both were fair producers. Early in the spring a well was completed on the Donnelly farm and flowed 125 barrels the first day. Other wells on this farm are much smaller. Two wells on the Grannan farm began flowing 75 and 90 barrels respectively. It is interesting to note that the development of this, the richest part of the Corning field, occurred late in the territory's history.

An important step in the development of the field occurred on August 13th, 1893, when the Buckeye Pipe Line was completed. Before that the oil was transported by tank cars. The oil is brought to the tanks partly by gravity and partly by suction, the latter being produced by an 8 horsepower gas engine, and is stored in two iron tanks, one of which has a capacity of 30,000, and the other of 28,000 barrels. From these tanks the

oil is forced to Elba, a distance of 34 miles, through a 4-inch line. This work is done by a 35 horse-power engine, which gives a pressure in the line of from 700 to 1,000 pounds per square inch. The rate at which the oil is transported varies with the temperature. In the summer, when the oil is warm, and hence thin, 128 barrels may be pumped in one hour, but in the winter, when the oil is cold and thick, the transportation may be restricted to 11 barrels for the same period.

When the pipe line was completed the production of the field was about 500 barrels per day. It increased to 1,300 barrels in 1896, but since then has declined. In June, 1900, it ranged from 800 to 900 barrels per day, but had dropped to 352 barrels in July, 1902.

Production.—The production of the field has been as follows, according to data furnished by J. R. Campbell, Treasurer of the Buckeye Pipe Line Company, Macksburg Division:

	Barrels.
Part of Year 1893.....	128,918.03
Year 1894	322,313.71
Year 1895	428,385.03
Year 1896	469,258.78
Year 1897	328,188.11
Year 1898	196,417.75
Year 1899	211,060.22
Year 1900	256,586.99
Year 1901	200,081.07
Year 1902	140,527.98

Leases.—At first the operators paid no bonuses, but gave a royalty of one-eighth of the oil to the land-owners—a rate that has been usually maintained. To this there is one exception worthy of note. When the round-house well showed the existence of oil, and operators began leasing the surrounding territory, Frederick Weaver, a thrifty German farmer, residing a short distance east of the round-house, quietly visited the oil fields of Washington, Pennsylvania, and investigated the methods of leasing oil territory in that field. When he returned home he demanded a royalty of one-fourth the oil and a bonus of \$200 for each of the eight wells which it was proposed should be drilled on his farm of eighty acres, and since his territory was regarded as very promising, these rather severe terms were granted. However, after drilling six wells, and the territory not meeting expectations, the contractors complained and Mr. Weaver generously reduced the bonus. More recently a royalty of one-sixth the oil has been received by holders of lands that were deemed especially promising, and bonuses also have been paid. The leases usually required that a well be drilled in from thirty to sixty days, but sometimes, especially in the least promising territory, six months were allowed.

That the field was a monopoly for no one is shown by the following list, which includes the chief operators of the district:

Corning Oil Company;	L. D. Langmade;
Denman & Thompson;	Harrington Brothers;
O'Connel Oil Company;	Ohio Oil Company;
Brooks Oil Company;	Church Oil Company;
Caldron & Snyder;	Monroe Oil & Gas Company;
Sunday Creek Oil & Gas Company;	Weaver Brothers;
Perry County Oil Company;	W. B. Irwin & Company;
W. B. Barker & Company;	George Best & Company;
Cleveland Oil Company;	Foster & Moran;
Keystone Oil Company;	Fallen Rock Company;
W. E. Detlor;	Ohlviler & Chambers;
William Rosier;	Mill Oil Company;
J. H. Van Wormer;	Hemlock Oil Company;
Northeast Oil Company;	John Holden;
Becker Oil Company;	Wells & Foraker;
Allen, Sternberg & Company;	Longfellow & Stevens;
Bolivar Oil Company;	Russell Metzger;
William McMullen;	McGee & Stewart;
A. Bulger & Company;	Stratton & Mark.
Corning Natural Gas Company;	National Oil Company.

Geology of the Region.—The surface of the territory lies in the Lower Productive and Lower Barren Coal Measures. The highest hills reach up to or extend above the Ames or Crinoidal limestone. In fact, along the northeast extremity of the field the hills are capped by the limestones, which underlie the Pittsburg coal. The deepest valley—that of Sunday Creek—cuts through the Middle Kittanning coal, a short distance north of Corning, but at this town the seam named is under cover, while the Upper Freeport coal is at about drainage level.

The succession of strata under ground is shown by the following record kept and furnished the Survey by Mr. G. W. Delong, Superintendent of Schools, Corning. The well is located on lot 154 of the town just named, and the top of the well lies at the base of the Mahoning sandstone:

	Thickness of stratum. Feet.	Total thickness. Feet.
Shale	25	25
Bastard lime	15	40
Sand	10	50
Coal (No. 6).....	10	60
White slate	65	125
Sand	15	140
White slate	25	165
Blue	10	175
Sand	10	185
Slate	50	235
Shale	35	270
Sand	30	300

	Thickness of stratum. Feet.	Total thickness. Feet.
Black shale	10	310
Lime	25	335
Shale with concretions	100	435
Slate	25	460
Limestone (?)	30	490
Shale	35	525
<i>Salt sand</i>	30	555
White slate	100	655
Slate and concretions	25	680
Shale	15	695
<i>Little Salt sand (Big Injun)</i>	20	715
White slate	100	815
Slate and concretions	100	915
Brown shale	40	955
Black shale (<i>Berea</i>).....	38	993
Top of <i>Berea</i>		993
Bottom of <i>Berea</i>		1,008

The Oil Sand.—This is in all cases the Berea. It has the light gray color so common in this formation in other parts of the state. It is moderately fine grained, but there is considerable variation in this respect. Usually it is a pure quartz sand, but occasionally has thin layers of dark shaley material running through it. In thickness it shows considerable variation, but never disappears in this field. The normal thickness is usually given as twenty feet and the maximum reported is eighty. This depth was found on the Potts farm about one and one-fourth miles northeast of Corning, and on the O'Farrell farm about two miles east from the same town. In both cases a dark gray shale, probably the Ohio, lay below. The Bedford on this theory had been swept away before the Berea was deposited. In such abnormal depths the additions always appear to be on the bottom, showing that the surface of the underlying Bedford shale was quite uneven. It is worthy of note that the production of oil does not vary as the thickness of the sand. In fact, in this field the great thicknesses are generally poor producers.

The pay-streak, or that containing the oil and gas, ranges in thickness from 3 to 8 feet, but very few wells attain the maximum figure. Towards the margin of the productive field the pay-streak thins, and finally disappears. The top of this usually lies from 10 to 15 feet below the surface of the Berea. As a rule the pay is coarser than other parts of the Berea, and generally the coarser the rock the larger the well. Sometimes in the thick part of the Berea there are two pay-streaks.

The Oil Wells.—The number of wells producing July 1, 1900, exceeded 600; August 1, 1902, it was 688. About 100 dry holes have been drilled and about an equal number of wells have been abandoned, so that 900 is a fair approximation of the total number of wells drilled. As a rule a well has been put down for each 8 or 10 acres of surface territory.

The wells have been cased through the Salt sand, a depth of 555 feet in the valley at Corning. The casing has almost invariably been $5\frac{1}{8}$ inches, inside measurement. The rocks comprising the underlying 160-180 feet, and terminating with the "Little Salt sand," have furnished some water, which has been disastrous to the wells. It reduced the gas pressure, thus necessitating pumping earlier than otherwise would have been required, and perhaps prematurely destroying the life of the well. Had the wells been cased through this sand time and money would have been saved, and the production of the field would have been larger.

The western side of the field is quite free from salt-water. It is on that side that the principal gas territory lies. On the eastern side the conditions are more variable. In Trimble township, Athens county, the wells are free from water, while in Monroe township, Perry county, salt-water is found in the northeast corner, and in Morgan county it is so abundant that operating is prevented. From this it appears that the western side of the Corning field is free from salt-water, and that it is absent also on the eastern side at the southern margin of the territory, but that it increases rapidly to the northeast.

While the production of the wells after being shot has varied greatly, yet they have not furnished the extremes that many other fields have. Few, if any of the wells, have started better than 125 barrels per day, and it has been estimated that the average for the entire field has been 20 barrels.

The wells have sufficient gas pressure to flow them during the earlier part of their lives, but later as the pressure diminishes they have to be pumped. Since the eastern side of the field has salt-water the wells there have to be pumped earlier than those on the western side.

The Gas Wells.—The principal gas territory is that along Muddy Fork in sections 22 and 29, Trimble township, Athens county, the best wells being found in the western half of the latter section on lands of the Hocking Coal and Railroad Company. The largest well in this field started at 3,000,000 cubic feet per day with a rock pressure of 400 pounds. It was drilled in the fall of 1897, and one year later was producing 2,000,000 cubic feet per day, and still another year later 1,500,000 cubic feet. Of the other wells in this territory two started at 2,000,000 cubic feet each, two at 1,000,000 feet each, and three at 500,000 feet each. The decline in the smaller wells was not as rapid as in the larger ones, since the demands made on them were not as heavy. The reliance of the community is on this field, where 5,000 acres are leased in one block. In 1902 the rock pressure had decreased to 200 pounds.

Another district that has yielded considerable gas is that at Oakfield, about 3 miles north of Corning. These wells started at 2,000,000, 1,500,000, 500,000 and 250,000 cubic feet per day respectively. Two of the smaller of these have been abandoned after having produced for two years. The largest

of these wells when 4 years old was producing 500,000 cubic feet per day. and the second largest when three years old was producing the same amount. These wells produce considerable oil and by some are rated as oil wells.

Outside of these two places an occasional strip is found that produces gas in paying quantities. Thus about one mile northeast of Corning two wells were drilled, which combined produced 500,000 cubic feet per day. They produced three years and were then abandoned. About two miles north of Corning a good well was drilled on the Newberry farm. It started at 1,500,000 cubic feet per day, had an initial rock pressure of 400 pounds and lasted three years.

Another productive tract lies about 6 miles northeast of Corning on the Finley, Devore and Stoneburner farms. Three wells were drilled on the Finley farm, and started one at 1,500,000 and two at 250,000 cubic feet, with an initial rock pressure of 400 pounds. These wells lasted three years.

The operators of the wells have been much troubled with salt-water in the Muddy Fork field and with oil in the Oakfield territory. Salt-water is removed by "blowing" the wells. For this operation the wells are closed for a short period, usually about 30 minutes, allowing the gas pressure to increase; when this has become sufficiently strong the well is opened at the top and the gas then blows the water from the well. When the well has been cleansed in this manner it is closed and the gas turned back into the mains. Sometimes, however, the weight of the water is so great that the gas cannot drive it from the well in the manner just stated; especially is this true with wells that have been in use for a considerable period. Then an iron rod attached to a long pole is let down through the water, is raised and lowered, and the gas following the pole in its ascent finally drives the water from the well. This method of cleaning is known as "agitating." Finally the pressure of the gas becomes so small that it cannot lift the water with the help of "agitating," and then the well is dead. In winter time each well is cleaned every other day, and in the summer twice a week.

The gas wells in the Corning field were owned and operated by the Corning Natural Gas Company, but recently they became the property of the Ohio Fuel Supply Company. It supplies Jacksonville, Trimble, Gloucester, Murray City, New Straitsville, Shawnee, Hemlock, Corning, Rendville, Moxahala, New Lexington, Nelsonville and several interior hamlets. Almost the sole use of the fuel is for heat and light for domestic purposes.

The company made a rate of 20 cents per thousand feet by meter.¹ Where the meter was not used, the prices in winter were \$2.00 per month for the first fire; \$1.50 for the second; \$1.00 for the third; 75 cents for the fourth, and all additional fires at the latter figure. In the summer a

¹The meter system seems to have been optional until October 1, 1901.

charge of \$1.50 for each cooking fire was made. For lights the charges were 25 cents each for the first two and 15 cents for each additional one. On October 1, 1901, the company adopted the meter system, the rate being 20 cents per thousand. The effect of this was economy in the use of gas, so that there was a supply for all, whereas before the supply was inadequate during cold weather. The change met with much opposition at first, but this was short-lived, and the wisdom of the new plan is now generally admitted.

The number of families supplied (1900) exclusive of Nelsonville, is approximately as follows:

Corning	300
Glouster	250
New Lexington	250
Shawnee	200
New Straitsville	150
Other places	350
Total	1,500

MUSKINGUM COUNTY.

This has never been an important producer of oil or gas. Nevertheless it must be ranked among the pioneer counties of the state in oil production. Few areas, too, outside of the large producers, have been more thoroughly tested. "Wells have been located in all the ways that can be suggested, viz., at the caprice of the drillers, at random, in the neighborhoods of the famous blowers of the salt-water days, and lastly, with all the aid that geology can give, on the summits of the low arches and terraces which the spirit level reveals, and the records of all agree as to the outcome. The order and character of the strata are remarkably uniform and regular, but there is nothing whatever to break the monotonous returns of complete and unrelieved failure. There is a little gas or oil, or both, everywhere, but the fatal flood of salt water is always just at hand, and the most brilliant promise is speedily extinguished by it."¹

Zanesville and Vicinity.—In 1884 the Zanesville Heating Company drilled a well in the valley of the river in Putnam. The well head was just below the Lower Mercer limestone. The Berea sand, having a thickness of 20 feet, was found at a depth of 840 feet, and was charged with oil. Work continued until the shales lying below the Berea had been penetrated to a depth of 1,149 feet, but without finding beds of sand or reaching the great limestone below. The well was a failure. A second well was begun soon. It was located two miles south of the city on the Bishop land in section 4 of Wayne township. The Berea sand was struck at a depth of 847 feet, and was 33 feet thick. It yielded a little oil and gas, but not sufficient for commercial purposes. In the spring of 1897 a well was drilled on the

¹*Geol. Sur. of Ohio*, Vol. VI, p. 376.

Fox farm about one mile east of Zanesville. The Berea made a small show of gas and with it much salt-water. From Zanesville the search has continued in all directions, and the various townships will be reviewed to show the thoroughness with which the tests have been made.

Blue Rock Township.—Pioneers of this township observed gas bubbling on the headwaters of Mann's Fork, and after oil had been discovered at Macksburg and Cow Run it was decided to drill a deep well in the hope of finding a pool of oil. The first well was drilled on the Daniel Border farm, and a show of oil was found at a depth of 80 feet. The next well, known as the Woodbury, was drilled on the Joseph McDonald farm. At a depth approximating 75 feet oil was found. The yield at first was from 40 to 50 barrels per day, but the decrease was rapid and by the end of perhaps two years the well was abandoned. This success started a boom, and it is estimated that within a year a hundred wells had been drilled in that locality. A hamlet known as Oil City, and with it the usual proportion of boarding-houses and saloons soon appeared. Within a year, however, it was found that the pool was small and the wells short lived. Soon the field was abandoned, and the only evidence now found of the former activity is an occasional piece of scrap iron, the remains of some crude drill or pump. Landholders received a royalty of one-fourth the oil, but notwithstanding this heavy ratio large bonuses in addition were sometimes paid. Several tracts, too, were sold at exorbitant prices, one piece of 13 acres commanding \$13,000. The oil is reported to have had a gravity of 26 degrees B. and to have been an excellent lubricator. The producing sand ranges in thickness from 2 to 30 feet, and lies about 70 feet below the "fossil" or Ames limestone. From this it appears that the oil sand is the First Cow Run. About 1870 an effort was made to drill a deep well in this territory, but at a depth of 500 feet the tools became fast and the well was abandoned. In the fall of 1900 two shallow wells were drilled on the Border farm, already mentioned. These were pumped a short time and then abandoned. In 1901 two wells were drilled near Rural Dale, but both were failures.

In 1886 Carr Brothers and Jewett drilled a well in section 32. The Berea sand, having a thickness of 14 feet, was found at 1,074 feet. It was torpedoed with 80 quarts of nitro-glycerine and made a good show of both oil and gas.¹ This was sufficient to encourage further exploration, and in 1887 a well was sunk on the Durant farm in section 31. The Berea was found 30 feet in thickness, but was of poor quality. It made a show of oil, but was abandoned without having been shot. About the same time a test was made along the river, one and one-half miles south of Gaysport. The Berea was reported 5 feet thick. The well was shot and made sufficient oil to warrant pumping, but in a short time salt-water ruined it. In the fall of 1900 a well was drilled on the Peyton farm, about two miles east

¹*Geol. Sur. of Ohio*, Vol. VI, p. 375.

of Gaysport. At a depth approximating 500 feet a show of oil was found, but the well was abandoned without reaching the Berea sand. Early in 1901 a well was drilled in the southern part of the township on the Finney land. The Berea made a show of gas, but this was overcome by a heavy charge of salt-water. About the same time two wells were drilled 3 miles east of Gaysport, one on the Cohagan and the other on the Shaver farms. Both were failures. In this part of the county, as well as farther south in Morgan, the Berea is divided. The relations are reported as follows:

Sandstone, 12-15 feet.

Shales, 6-15 feet.

Sandstone, 12-20 feet.

The drillers apply the name Berea to the upper division only, the lower one being known as the "stray." One experienced driller reports that the sand separating the two has a red color, a character indicating that it belongs to the Bedford. Oil and gas when found are in the upper division.

Brush Creek Township.—About 1897 a well was drilled on the Swingle farm in section 8. It was located on the bank of Brush creek and reached the Berea sand at a depth of 1,096 feet. Considerable gas with some oil was found, and the well was pumped a short time. In 1899 a well was drilled on the Longshore farm in section 15. A skeleton record of this well, furnished by T. P. Connar, is as follows:

	Thickness of formation. Feet.	Depth to bottom of formation. Feet.
Putnam Hill limestone	3	23
Sub-Carboniferous limestone	40	265
Big Injun sand	40	630
Berea shale	33	952
Berea sand	28	980
Bedford shale	30	1,010
Bottom of well at 1,030 feet.		

All measurements were made with a steel line.

The Berea made a show of oil, and with it some salt-water. In 1900 a well was drilled on the Swingle farm in section 9. The sand was found at 1,155 feet, and produced some oil and gas. After having been torpedoed with 80 quarts of nitro-glycerine it began flowing oil and is said to have produced between 200 and 300 barrels. It was never pumped. Within the same year a well was drilled on the Boyd farm in the same section. It made some gas and a small quantity of dark colored oil. The well was abandoned. Mr. Connar reports a reversal of dip in this locality, the dip to the west being 24 feet in less than one and one-half miles. On the eastern side of the arch the dip is 65 to 68 feet per mile. The wells are on the west side of the arch.

Harrison Township.—In 1900 a well was drilled on the Durant farm in section 31. The Berea sand found was of poor quality, and contained salt water, but neither oil nor gas. In the same year a well was drilled near Cedar Run P. O. on the bank of the Muskingum river. The Berea was reached, but contained neither product sought.

Newton Township.—On the Beem farm in section 34 a well was drilled in 1897. The Berea sand, 11 feet thick, was found 887 feet below the surface. Both oil and gas were found but not in commercial quantities, and the well was abandoned without having been torpedoed.

Cass Township.—A well was drilled at Dresden in 1886. The Berea sand having a thickness of 14 feet was found 768 feet below the valley, and contained oil and brine. Work continued until several hundred feet of the Ohio shales had been passed through, and then not having met with any further encouragement the well was abandoned.

Meigs Township.—At least two deep wells have been drilled in this township. One located on the Bethel farm is reported to have produced some gas, and to have made a show of oil. Data concerning this well are very meager. It is probable, however, that the Berea sand was reached. About the year 1893 a well was drilled on the Simms farm 4 miles east of High Hill. A depth approximating 1,700 feet was attained. The sand made a show of oil, but the well was abandoned without having been shot.

Salt Creek Township.—About 1892 a well was drilled on the Cline farm in section 28. The Berea sand was found at a depth approximating 1,085 feet, but contained neither oil nor gas in commercial quantities. About the same time a well was drilled on the Murphy farm in section 28. Nothing better than a show of oil was secured. Neither of these wells was troubled with much salt-water. A well was drilled near the same time on the Evans farm in section 33. The Berea contained some black oil, but the well like the others in the township was abandoned.

Perry Township.—About 1898 a deep well was drilled near the village of Sonora. The sand contained salt-water, but neither oil nor gas.

Rich Hill Township.—Three wells have been drilled near Freeland within the past few years. One on the Abraham Howell land found the Berea at 1,350 feet. The sand was not drilled through. It made a good showing of oil, but was not pumped. Similar results were had in the other two wells.

Jackson Township.—The only deep well ever drilled in this township was located about three miles north of Frazersburg on land now owned by William Normans. A depth of 760 feet is reported. It produced much salt-water and a show of gas. This well is said to have been drilled more than 30 years ago.

Licking Township.—In 1901 a well was drilled on land of John Nether in lot 12. The Berea is said to have been drilled through, but nothing of value was secured.

Salem Township.—In 1899 a well was drilled on land of E. B. Shivers two miles east of Adamsville. The Berea grit, 20 feet thick, was found at 1,176 feet. It made a showing of oil and gas and much salt-water. In the same year a well was drilled on the farm of C. A. Geyer near Adamsville. The Berea was found at 1,200, and was 28 feet thick. Total depth, 1,255 feet. The results were similar to those of the preceding well. Both wells were shot with 60 quarts of nitro-glycerine.

ATHENS COUNTY.

This discussion will include all townships of this county except Trimble, which forms part of the Corning field, and Ames and Berne, which have been discussed in connection with Morgan county.

Athens Township.—The earliest wells of which report was received were drilled along Sugar creek in the northern part of the township, many years ago, perhaps about 1865. No positive information was received as to the depths of these. One is reported to have produced a small quantity of oil.

Of the recent wells drilled in this township the first was on the farm of J. T. Hope, about one and one-half miles west of Athens, in the fall of 1895. The depth of this well was 1,050 feet and the thickness of the Berea 40 feet. The well produced considerable gas, but no oil. The middle of the Berea was charged with salt-water. No use was made of the gas, and so the casing was withdrawn and the well abandoned.

In December of the same year a well was drilled in the Stroud's Run field on the C. A. Snow farm, about 3 miles northeast from the court house. This point is on a line extending from the oil wells in Trimble township to several small gas wells southeast of Athens, and for this reason it was thought that the location might be in productive territory. The depth of this well was 1,250 feet. It showed some oil and gas, and the production was increased by shooting with 40 quarts of nitroglycerine. Another well in this field was drilled in April, 1896, 2 miles north of the last one on the F. L. Junod farm, and was dry. On May 30, 1896, a well was completed on land belonging to George Slaughter, about 1,000 feet west of north of the one on the Hope farm. It produced a small amount of gas, but no oil. In the fall of 1896 a second well was drilled on the C. A. Snow farm, about 500 feet east of south of the first well drilled. Some oil was found, but this was driven out by a flood of salt-water, and the well was abandoned without having been shot. Two wells were drilled in this field in 1900, one of which was producing 12 barrels per day on July 1st, but the other one had not been tubed at that time. It is safe to say that the production of this field, which occupies a fraction only of one mile, does not exceed 25 barrels per day. Quite recently a two-inch pipe line has been laid

by the Buckeye Pipe Line Company, connecting this field with the B. & O. railroad just east of Athens. From that point the oil is hauled in tank cars to Parkersburg, the charge being 15 cents per barrel. In September, 1902, the 4 wells in this field were making all told about 10 barrels per day.

The bottom of the Berea sand is charged with brine, and so the drill is not driven through it. Usually the sand is penetrated to a depth of from 15 to 18 feet. Thus far the show of oil in the field has been simply enough to make certain further explorations, and in the autumn of 1899 the Athens Oil and Gas Company was formed to develop this territory, of which it had 700 acres leased.

Several wells have been drilled within the past few years on the Children's Home farm, just outside of the Athens corporation, and on lots within the city limits. In January, 1897, a well was drilled on the Home farm, about 300 feet north of the Hocking river. The Berea was found at 1,135 feet, and contained water charged with salt. When the Berea was penetrated a show of oil and gas was found, and this was materially increased by shooting the well with 40 quarts of nitro-glycerine. The well was pumped about 30 days, after which it was tubed when it began flowing. The yield of oil was about 2 barrels, and of gas about 75,000 cubic feet per day. It is claimed that the yield of these products at the present time is similar to that at the beginning. Another well was drilled on the Home farm in June, 1897, and practically duplicates the one previously reported.

Two wells were drilled near Mills street in Athens in the summer of 1898. Both produced oil and gas, but the latter was not sufficiently strong to force the oil to the surface and so the well had to be pumped. The two conjointly produced one barrel of oil per day. The gas is turned into the city mains.

In the summer of 1898 a well was drilled on the Governor farm just north of the Home, but the Berea sand was wanting and the well consequently dry.

Two wells have been drilled on the grounds of the Athens Brick Company. The first, which was finished in April, 1898, struck the pay-rock at a depth of 1,144 feet. It produced no oil, but yielded sufficient gas to supply a dozen residences. The second well, finished in August, 1898, duplicated the first one, except that it was even smaller. Because of the fear of salt-water the first well was never shot, but the second one was shot with 35 quarts.

Waterloo Township.—With the exception of Athens and Trimble more deep wells have been drilled in Waterloo township than in any other one in Athens county.

The stratigraphical relations are shown by the following record of a well located one mile northwest of Marshfield. Mr. W. R. O'Neill, well contractor, has kindly furnished the Survey with the data.

	Thickness of stratum. Feet.	Total depth. Feet.
Surface material	19	19
Shale	81	100
Soft white sand	65	165
Coal	7	172
Shale	112	280
Coal	10	290
Shale	285	575
Soft sand	10	585
Shale	85	670
Shale	472	1,142
<i>Berea sand</i>	30	1,172
Shale	10	1,182
<i>Berea sand</i>	40	1,222
Shale	772	2,000
Brown shale	350	2,350
Shale	100	2,450
Brown shale	68	2,518
<i>Corniferous and Lower Helderberg lime...</i>	200	2,718

It will be noted that according to this report the Berea consists of two strata separated by ten feet of shale, a condition that becomes quite conspicuous in Morgan county and other places. This well was a failure.

Following is the record of a well one mile south of Mineral on the farm of Henry Graham, finished June 6, 1900; furnished by Mr. W. R. O'Neill, well contractor.

	Thickness of stratum. Feet.	Total depth. Feet.
Surface	20	20
Slate	95	115
Sand	125	240
Slate	30	270
Sand	30	300
Red Rock	10	310
Limestone	40	350
Slate	20	370
Sand	50	420
Slate	20	440
Limestone	40	480
Sand	60	540
Slate	140	680
Sand	40	720
Slate	70	790
Limestone	60	850
Slate	50	900
Sand	40	940
Limestone	20	960
Slate	50	1,010
Brown slate	18	1,028
<i>Berea sand</i>	27	1,055
Bedford shale	5	1,060

To the above may be added the following additional record of a well drilled in the same vicinity by the Ohio Oil Company.

	Feet.	Feet.
Berea grit	34	1,041
Ohio shales	1,230	2,271
Helderberg and Niagara limestones	816	3,087
Clinton Series—Brown shales.....	15	
Red shales.....	10	
Shales.....	124	3,236
Medina shales (red)	10	3,246
Light gray shale	9	3,255

The company was drilling for the Clinton sand, but as shown this was not present, its place being occupied by shales.

Other deep wells in this township have been sunk in sections 17, 18, 19 and 25. In fact this territory and the adjoining parts of the counties on the west and south have been tested by the Ohio Oil Company, which has extensive leases in this part of the state. The result of these tests has been to demonstrate that oil and gas are not found in paying quantities in the territory under consideration. There are rumors and reports of good wells in Waterloo township, but there is good reason to believe that the best wells do not produce more than three barrels per day.

York Township.—Three wells have been drilled here and all were failures. One was located in section 1, another at Nelsonville, and the third near Buchtel.

Lee Township.—Two wells have been drilled in this township, one on the John Elliot farm in section 17, which was dry, and the other in the village of Albany. The latter one made a showing of dark oil, but the quantity was so small that the well was abandoned.

Alexander Township.—Three Berea wells have been drilled in this township. One at Hebardsville on land owned by Henry Merick, drilled in the autumn of 1895, made a good showing of heavy oil, but the production was not sufficiently large to warrant operating, and so the well was abandoned.

In the winter of 1895 a well was drilled on the Cooley farm, situated about 2 miles south of Hebardsville, and a good flow of gas was found. This is reported to have been measured by the mercury gauge, and to have produced 1,222,000 cubic feet per day. Not satisfied with this the operator proceeded to drill deeper, but struck a heavy flow of salt-water which ruined the well. The third well was drilled at Zelda, but was dry.

Canaan Township.—A well was drilled on section 34 in the autumn of 1896. The Berea was struck at about 1,220 feet, and was 24 feet thick. It was underlaid by the red Bedford. In attempting to shoot the well, the 40

quarts of nitro-glycerine were accidentally discharged at a depth of about 900 feet, bursting the casing and necessitating the abandonment of the well. Before shooting, the well is reported to have made a good show of both oil and gas. In 1898 a well was drilled in section 33, and began flowing 5 barrels per day. In 1899 a second well was begun in this section, but at a depth of 470 feet gas was struck and the wells were connected with the Athens mains. The company expected to drill the well to the Berea later.

Dover Township.—Three Berea wells have been drilled here. They were located in sections 1 and 2 and along the Athens township line near where the Hocking river leaves Dover. Nothing more than a small flow of gas was found, and the wells were abandoned.

Lodi Township.—A Berea well has been drilled on the farm of Lewis Jeffers about one mile north of Shade P. O. At a depth of about 500 feet considerable gas was found, but when the well was extended to the Berea neither oil nor gas was present. Two wells have been drilled near Hull P.O., in the eastern part of the township. The first was on the farm of Geo. R. Lawrence, just east of the village named. The Berea is reported divided there as shown below:

	Feet.
Sand	25
Slate	25
Sand	25

Oil, gas and salt-water were all found in the upper sand, and in the lower one the gas was so strong that it cleaned the well. No use was made of it however, and the well was abandoned. A well has been drilled on the Eliza Hull property in the village of Hull P. O. The well was cased through the top of the Berea and shot with 60 quarts of nitro-glycerine, but because of an accident the well was abandoned. A Berea well has been drilled in section 12, and another one across the line in Carthage township in section 35, less than a mile northeast of Hull. Neither of these made more than show of oil or gas.

Troy Township.—A Berea well was drilled on the Shepard Humphrey farm one mile south of Coolville about 1898. The hole was dry and was abandoned without shooting. Another failure was recorded in a well one-half mile west from the same village. It made a small showing of oil, but was never shot.

Rome Township.—The only Berea well in this township was located on the northeast quarter of section 31. Like nearly all the wells in the county it was a failure.

Summary for County.—More than 50 wells have been drilled to the Berea and not one good producer found. It is safe to say that the total production of these wells is less than 35 barrels per day. The companies which have recently been or are now (1900) operating in the field are the following:

Shepp Oil Co.
Athens Brick Co.
Ohio Oil Co.
Bradley and Co.
Paova Oil and Gas Co.
Athens Gas and Oil Co.
Hocking Oil Co.

Remembering that one or more Berea wells have been drilled in each township with the results as recorded, it seems safe to say that no large pools of Berea oil lie within the limits of the county.

HOCKING COUNTY.

A large number of wells have been drilled in this county. In 1865 and 1867 three tests were made to the Berea grit at Logan. The top of the wells was at the horizon of the Logan Conglomerate, and the Berea was reached at about 600 feet. All yielded a small quantity of heavy oil, and from one the production was continued for several years. In 1887 another test was made at the county seat, and the result was similar to that obtained from the earlier wells.¹

About the time that the early wells were drilled at Logan three tests were made of the Berea grit near Bloomingville, Benton township. The sand was struck at a depth of about 500 feet, with results similar to those in Logan. In 1882 another well was drilled in the same vicinity, the Berea again producing a small quantity of both oil and gas. No use was made of either, however. In 1896 a company of McArthur citizens drilled a well in this township. It was located on the Miller farm in section 33, and struck the Berea grit at 526 feet. The sand was penetrated to a depth of 14 feet without reaching the base. After having been shot the well yielded a small quantity of heavy oil of about 26 degrees B. gravity. In 1902 a well was drilled on the Honold farm in section 36. The Berea is reported to have been found at 728 feet, and to have yielded a small quantity of lubricating oil of excellent quality. Both wells contained considerable salt-water in the Berea. Doubtless other wells will be drilled to the same horizon in this township.

Besides the Berea wells one has been sunk to the Clinton. This was in the southern part of the county, just north of the small pool in Jackson township, Vinton county. The well, however, was dry. Two other attempts have been made to reach the Clinton in this part of Hocking county, but both were unsuccessful.

The northern part of the county under consideration has been as productive as other parts have been barren. Reference is made to Good Hope,

¹*Geol. Sur. of Ohio, Vol. VI., pp. 391-93.*

Laurel and Marion townships, which constitute an important part of the famous Sugar Grove gas field. This has already been considered in that connection, and no further discussion of it is necessary here.

JACKSON COUNTY.

The surface formations of the greater part of this county lie in the Conglomerate Coal Measures, and the Allegheny Formation, or as it has long been known the Lower Productive Measures. Along the western side of the county the Waverly is found. The amount of drilling has not been as extensive as in several adjacent counties. Thus far negative results only have been secured.

Lick Township.—In 1886 a deep well was drilled at the county seat, and a depth of 1,636 feet reached. The Berea grit was found at 750 feet, and has a thickness of about 8 feet. It made a show of oil and gas, sufficient of the latter to supply one residence. The well was not torpedoed. Much salt-water was found in the great limestones lying beneath the Ohio shales. The well head is reported to have been about 50 feet below the Sharon or No. 1 coal. Encouraged by this well another one was begun almost immediately near the western limit of the town, the objective stratum being the Berea. This was found at about 740 feet, and made a show of oil and gas, but neither in quantity to be commercially valuable. No further work has been done in the township.

Wellston Township.—The only test reported here was made at Wellston in the summer of 1902. A depth of 800 feet was reached, which was probably sufficient for the horizon of the Berea grit. The only reward was a small show of oil and gas. The well head is reported at about 85 feet above the Wellston or No. 2 coal.

Liberty Township.—A deep well was drilled by T. N. Barnsdale on the land of I. C. Long in 1898. The top of this well is reported to have been on the horizon of the Sharon or No. 1 coal. It was planned to drill to a depth of 3,300 feet, but work stopped at 2,155 feet, and the well was abandoned, leaving 600 or 700 feet of casing in it.

Scioto Township.—A well has recently been drilled on land of Van Johnson, but without success.

Jackson Township.—Two or more wells are reported in this township, which lies in the northwest corner of the county. A show of oil or gas was secured, sufficient to induce the operators to make more than one test, but the results have been out of proportion to the time and money expended.

It appears in view of wells already drilled that a show of oil or gas can be found in the Berea grit almost anywhere in the county. There is no reason to believe, however, that either of these will be found in quantity ample to be profitable.

Washington Township.—About 1891-2 a well was drilled in the north-east corner of this township near the Baltimore and Ohio railroad. The Berea grit is reported to have been struck at about 900 feet, but was dry.

VINTON COUNTY.

The surface geology in this county is similar to that in Jackson. Along the western margin the Waverly constitutes the surface formation, but elsewhere the coal measures are found. Drilling has been done at times during the past 35 years; at first the Berea was the stratum sought, but when this did not yield satisfactory results deeper holes were drilled. During the past ten years about a dozen tests have been made in the Clinton, the details of which are given under the several townships. Nearly all the deeper wells are found on the western side of the county.

Vinton Township.—The first deep well in the county was located on the John Calvin farm in section 4 of this township. It was drilled in 1867, and struck a heavy flow of gas at 490 feet. The well head is reported to have been near the Ferriferous limestone, and consequently the gas sand could not have been the Berea grit. Probably it belonged in the Logan group. The gas when ignited produced a flame from 75 to 200 feet high, and as late as 1870 showed little or no diminution.¹ About ten years after the well had been drilled, during all of which time gas had been wasting, it was cleaned with the idea of using the gas in the manufacture of lamp-black. However the time had passed for such a supply, and the well soon ceased flowing entirely.

In 1895 H. C. Chapman drilled a well about 600 yards north of the pioneer one. The well-head was at about the horizon of the Ferriferous limestone, and the Berea grit was found at 1,015 feet. Both gas and salt water were found in the Big Injun, and the same is true of the Berea. The depth of the well was 1,055 feet, work having stopped when the drill had penetrated a few feet of the shales underlying the Berea.

Below is a log of this well, furnished the Survey by J. M. McGillivray, Esq., of McArthur:

	Thickness of formation. Feet.	Depth to bottom of formation. Feet.
Loam	25	25
Sand	35	60
Coal, 3a	3	63
Limestone	8	71
Black shale	20	91
Sandstone	27	118
Slate	45	163
Sandstone	6	169
Coal, No. 2	2	171
Slate	63	234

¹ *Geol. Sur. of Ohio, Vol. VI., p. 394; also Report of Progress (1870), p. 118.*

	Thickness of formation. Feet.	Depth to bottom of formation. Feet.
Sandstone	21	255
Slate	6	261
Limestone	81	342
Slate	33	375
Sandstone	80	455
<i>Big Injun</i> —Cased at 795 feet.....	240	795
Shale	220	1,015
<i>Berea sand</i>	38	1,052

In the same year Mr. Chapman drilled a well on section 24. The Berea was struck at about 1,000 feet. It liberated a flood of salt-water and made a show of oil.

In 1899 the Ohio Oil Company drilled two holes in this township; one was near the Eakin well in section 4, the other on the Wyant land in section 13. Both stopped with the Berea grit. A show of oil and much salt-water were secured.

Clinton Township.—About the year 1886-7 a well was drilled at the village Hamden, and the Berea reached at a depth reported at 900 feet. A show of gas and perhaps of oil was the only reward. The salt-water found was in sufficient volume to flow from the well. In 1902 several shallow wells were drilled in this township, and sufficient gas found to warrant piping Hamden. The producing sand lies above the Berea, and probably forms part of the Big Injun series.

Madison Township.—About the year 1895 a test was made on the Verigan farm in section 26. The Berea, which was found at about 1,000 feet, made a show of oil and much salt-water.

Brown Township.—But one well has been reported in this township. This was on the Thomas McGee farm in section 34. The work was done about 1895. The Berea was found at approximately 1,000 feet, and made a show of oil and much salt-water.

Richland Township.—In the spring of 1898 a well was drilled on the south side of section 4. Work did not cease until the Clinton sand had been struck, but it yielded neither oil nor gas. Shortly afterwards a well was drilled on land of William Poland in section 28. The Clinton was found at 2,340 feet, and is reported to have made a heavy flow of gas. No use seems to have been made of this fuel, however. This well was followed by another one, located on the Wyatt land in section 9, near the north line of the township. The Clinton sand at first made much gas, but this was soon exhausted. Not satisfied with these results another well was being drilled to the Clinton in the winter of 1902-03.

Jackson Township.—This township contains a small but the best pool of oil that has yet been found in the county. It lies in sections 3 and 4 near the Hocking county line, and was discovered in August, 1899. By

September, 1902, five oil and one gas wells had been secured and two dry holes drilled in this section. Two additional dry holes have been drilled to the Clinton in this vicinity; one on the McNichols farm in the northeast quarter of section 8; the other on the Westcoat farm in the northwest quarter of section 22. Further, a dry hole was drilled in Benton township, Hocking county, just north of the pool under consideration. These failures pretty thoroughly surround the producing territory and leave little hope for an important extension.

The production of oil in the early summer of 1902 was 125 barrels per day, only four wells having been completed at that time. In September of the same year the five wells yielded 109 barrels per day. The initial production of the wells ranged from about 10 to 70 barrels each per day. All flowed at first, but with one exception had soon to be pumped. The gas well is reported to have had an initial rock pressure of 650 pounds per square inch, and an open flow of 750,000 cubic feet per 24 hours.

A log of the McNichols well has already been given in the chapter treating of the Central Ohio Natural Gas Fields. One additional record will be given. This is the M. J. Hill well No. 3:

	Feet.
Drive pipe (8 inch).....	18
Casing 6½ inches	760 feet
Top of Corniferous limestone.....	1,570
Bottom of Niagara limestone.....	2,270
Casing 5 13-16 inches.....	2,413 feet
Top of Clinton sand.....	2,428
Bottom of Clinton sand	2,443
Total depth ..	2,449
Tubing, 2 inch	2,449 feet

The sand differs much in color from that found in the Sugar Grove and Homer fields, being much darker. In fact it sometimes becomes red-brown.

The success of these wells produced considerable interest among oil men, and large areas were leased in this and adjoining townships. The prevailing rental has been 50 cents an acre per year.

Knox Township.—This lies along the eastern line of the county. A number of wells have been drilled in it, especially on sections 22 and 23. The objective formation in these has been the Berea grit, and a small production of oil has been secured. Results thus far do not indicate that anything of marked value will result from these wells.

Swan Township.—In 1901 a well was drilled on the Cradlebaugh farm about one mile south of the station, Orland. The Clinton sand, which was found at a depth of about 2,900 feet, began flowing gas at about the rate of 400,000 cubic feet per day, the closed or rock pressure having been 690 pounds per square inch. Encouraged by this result a second well was drilled the following year on land of Robert Wadsworth, about one-half

mile north of the Cradlebaugh well. The Clinton sand in good quality was found at 2,811 feet, but was entirely dry. Both wells were drilled by the Ohio Oil Company.

GALLIA COUNTY.

The search for oil in this county began at an early day. In the spring of 1861 a well was begun on section 30, Addison township. It had reached a depth of 150 feet when the Civil War began, and drilling at once ceased, the workmen enlisting in support of their country. No further work was done until the war closed, and the well begun in 1861 was never finished.

The first complete oil well ever drilled in the county was in 1865 on land of John Martindale in section 30, Addison township. The well was about 74 feet deep, and during 40 days produced perhaps 12 barrels of oil per day. The oil was thick and heavy, and was sold for lubricating purposes. The company's receipts show that about 500 barrels were sold. After having pumped the well for 40 days with the results as reported, eastern parties visited the field and persuaded the owners that if they would drill deeper a flowing well would be secured. The advice was heeded, but the results promised did not follow, and what was worse the old well was ruined. During several years following a number of wells were drilled in the neighborhood, and all produced oil, but not in paying quantities. In 1898 nine wells were drilled on farms belonging to John Martindale, Enos George, Owen Thomas and E. M. Fulton, and oil was found in all with a single exception, but not in paying quantities.

In 1865 a well was drilled at Adamsville on the east side of Raccoon township along the east bank of the creek of the same name. The total depth of the well was about 800 feet, and the rock was there unproductive. At 400 feet considerable gas was found, and it is said to be escaping at the present time. Quite recently a well has been drilled in the southeast corner of Raccoon township. A show of oil was secured in the Berea, but the drill liberated a flood of salt-water and the well was a failure. The following log of this well, and the information relating to the county were kindly furnished the Survey by Mr. J. W. Jones:

	Depth of stratum. Feet.	Total depth. Feet.
Surface material	26	26
Sandstone	42	68
<i>Slate, Coal No. 6 A and clay</i>	5	73
Sandstone	26	99
Shale	13	112
<i>Middle Kittanning coal No. 6</i>	7	119
Clay and slate.....	67	186
Coarse sandstone	7	193

	Depth of stratum. Feet.	Total depth. Feet.
<i>Ferriferous limestone</i>	7	200
Coarse sandstone	25	225
Sandy shale	23	248
Sandstone	42	290
Slate	39	329
Sandy shales	74	403
Coarse sandstone	42	445
Black slate	55	500
Limestone and slate.....	70	570
Sandstone	16	586
Coal (No. 1?).....	1	587
Sandstone, Salt-sand	506	1,093
Shale	31	1,124
Sandstone	41	1,165
Cuyahoga shales	145	1,310
Berea shale (Black).....	20	1,330
<i>Berea grit</i>	15	1,345
Blue shales	8	1,353
Red shale (Bedford).....	60	1,413
Ohio shale	4	1,417

The Salt sand in this record is very unusual. It doubtless includes everything from the top of that formation to near the base of the Big Injun.

Mr. Jones has run the Y level from the surface of the well to the summit of the adjacent hills with the following results:

	Feet.	Feet.
<i>Upper Cambridge limestone (top of hill)</i>	2	2
Red clay	7	9
Hard sandstone	2	11
Shale	21	32
<i>Lower Cambridge limestone</i>	3	35
Slate	15	50
Red shale	5	55
Slate and shales.....	26	81
Sandstone	28	109
Slate	15	124
<i>Coal No. 7 (U. Freeport)</i>	2	126
Clay	2	128
Slate	18	146
Red shale	4	150

On the Betz farm in Addison township a well was begun in the year 1889 probably. It was located by a forked stick and the "smeller" reported the producing territory $23\frac{3}{4}$ yards long, $9\frac{3}{4}$ yards wide, and of unknown depth. It was expected that oil would be found at a depth of 500 feet, and the company lacked funds to push the work further. Pro-

gress was very slow. At one time nothing was done during 4 years, and not until about 1898 was the Berea struck. The production of oil was from $1\frac{1}{2}$ to 2 barrels per day before shooting, and less afterwards.

A Berea well was drilled on the William Boice farm adjoining the Betz in 1899. It made a showing of oil, but was never shot. About one mile west from the Betz farm a Berea well was drilled in 1899 on the Cole property. It never made more than a showing of oil, but produced considerable gas. About one-fourth of a mile south of the Betz, a Berea well was drilled on the Swisher farm. It produced about 2 barrels per day. In August, 1900, a well drilled near the center of section 34, Addison township, struck the Berea at 1,503 feet. The rock was fine grained and had a thickness of 11 feet. It contained some gas and produced one-half barrel of oil per day.

In 1887 a deep well was drilled on the land of John E. Mills, near Mills Station, by the Gallipolis Natural Gas Company. A heavy oil is reported to have been found in a 4 foot seam of coal at a depth of 325 feet. A 7 foot seam is reported at a depth of 578 feet. It should be borne in mind, however, that such data in so far as it refers to coal beds is very unreliable. The drillings of the reported seam are reduced to mud, and a soft dark shale when ground up in this manner may be readily taken for coal. Besides the measurements may be incorrect. A heavy string of tools, such as is used in deep wells, passes through coal seams so rapidly that the driller is liable to err in his measurements. Especially is this true when the steel measuring line is not used, which is commonly the case. Veins of brine were found at 678, 730, 930, 1,213 and 1,475 feet. The Berea was struck at 1,475 feet and was 32 feet thick, but contained nothing more than salt-water. From a shelly sandstone, 3 feet in thickness which was struck at a depth of 2,458 feet, one barrel of lubricating oil was secured. The Corniferous limestone was reached at 2,865 feet and the drill was forced on to a depth of 2,910 feet, when the tools became fast and the well was abandoned. A log of this well may be found in the Pennsylvania Second Geological Survey, Vol. XV., page 335.

A deep well was begun May 14, 1896, on Keton's run in Huntington township. It passed through 15 feet of Berea sand and reached a total depth of 1,765 feet, but nothing was secured to compensate the operator for his time and money.

The production of oil and gas in the county, it will be seen from what has just been said, is comparable to that in Athens county. That found up to the present time has been insignificant in comparison to the money expended. In fact the yield has been sufficient merely to lead the operator on and on in hope of finding a large pool. The outlook for a good production of either oil or gas in this county is not promising.

MEIGS COUNTY.

The existence of oil and gas in this county was discovered in drilling for salt. Somewhere between 1830 and 1840 a well drilled for that product near the mouth of Leading creek in Rutland township, found some oil and gas. The first well in Meigs county that ever produced oil to any commercial extent was drilled about 1852 in Pomeroy near the line separating that city from Middleport. The well was drilled for salt, but at a depth somewhere between 200 and 400 feet oil was found. It flowed into a ravine and then into the river. Finally, lest the oil might set fire to the boats, a dam was built in the ravine. Nearly 100 barrels of this oil were shipped to St. Louis where it was sold as a liniment.

Somewhere between 1855 and 1865 a well was drilled about $1\frac{1}{4}$ miles northwest from Rutland in Rutland township. At a depth of 830 feet a dark lubricating oil was found. The surface of the well is reported at about 50 feet below the Pomeroy coal (No. 8) seam. The well is still producing but in quantities so small that the oil is not saved. Between 1880 and 1885 a well was drilled a few yards from the last one on the Rightmire farm. Oil was found in small quantities at about the same depth as in the neighboring well, but drilling did not cease until a depth of 1,971 feet was reached. No valuable deposits were found. Later another well was drilled in the same vicinity by farmers. Without being shot, oil and water were thrown to the top of the derrick, but the operators quarreled and the well was abandoned. A short distance southwest of these wells another one was drilled about 1890 on the Savage farm along the border of Salem township. Oil was found, but the operators ran out of funds and the well was abandoned.

Near Minersville several wells were drilled for salt. At a depth of about 475 feet oil or gas was found. From one the oil flowed so freely that it ran into the river. The oil and gas were shut out by casing, however, and the wells used for salt.

In the early sixties Thomas fork, which lies about $1\frac{1}{2}$ miles back from Pomeroy, was a small oil field. Between 15 and 20 wells were drilled, some as deep as 300 feet, but the greater number were less than 150 feet. Several hundred barrels of oil were shipped from the Highland well to Marietta. Drilling is still being done in this locality.

In 1894 a well was drilled to a depth of 1,780 feet on the Carr farm along the eastern line of Salisbury township. Some gas and a small show of oil were found, but the well was abandoned. North of Enterprise, in the same township, a well was drilled for oil in the sixties. Considerable gas but no oil is said to have been found.

About 1894 a well was drilled to a depth of 2,500 feet on the Devlin farm in Olive township. It made a showing of both oil and gas, but the well was abandoned. This territory is now (1900) leased by the Carter Oil Company.

More than 15 years ago Oscar Chase drilled a well on his farm in Rutland township. The drill reached a depth of perhaps 1,000 feet. Only a showing of oil was found, but there was sufficient gas to heat and light his residence.

Several wells have been drilled to a depth of about 1,000 feet near New Lima. All made a showing of oil, but beyond this there was nothing to reward the operator.

KNOX COUNTY.

In 1884 a deep well was drilled on the bank of Owl creek south of the Baltimore and Ohio station, Mt. Vernon. The Berea sand was struck at a depth of 478 feet and was 30 feet in thickness, but contained salt water only. The drill was kept at work until the underlying Bedford and Ohio shales were drilled through, and the Devonian limestone penetrated to a depth of 78 feet, when an accident occurred and the well was abandoned. A thickness of 1,000 feet was reported for the Ohio shales, but from a record shown on a later page this appears too large. At the bottom of the drift, which was 87 feet thick, a heavy flow of fresh-water was secured, and this now furnishes part of the city's supply.

This failure, however, did not convince those interested that the territory was lacking oil and gas in commercial quantities, and arrangements were made to continue the exploration. About two years later a well was drilled on the farm of Thomas Banning, two miles north of the city limits. The depth reached is reported to have been nearly 2,000 feet. A light flow of shale gas was the only reward for the heavy expenditure of labor and money. In the same year a well is reported to have been drilled on land of George Simpkins 4 miles northeast of the city. The depth was about 200 feet less than in the Banning well, but the results were similar. In the spring of 1887 a well was drilled near the city limits. The Berea 20 feet thick, was struck at a depth of 453 feet, and 887 feet below the Berea the Corniferous limestone was found. Work continued until the Lower Helderberg and Niagara limestones had been passed through. The total depth of the well was at least 2,600 feet.¹ About this time the city of Mt. Vernon, acting under authority of the legislature, provided \$10,000 to continue the investigation. The objective stratum was the Clinton, since it had already been shown to contain valuable reservoirs of gas at Lancaster, Thurston and Newark. Two contracts provided that a depth of 3,500 feet should be reached, with the hope of finding the Trenton which had shown such unexpected results in Northwestern Ohio. The first of these wells was completed in the fall of 1889, and because of the light that it throws on the thickness of several members of the Ohio Geological column, the following record taken from Dr. Orton's report is here given in full.²

¹*Geol. Sur. of Ohio, Vol. VI., p. 367.*

²*Geol. Sur. of Ohio, First Ann. Rep. (1890), p. 244.*

	Feet.
Drift	244
Cuyahoga and Berea shales	173
Berea grit, carrying salt water	38
Bedford and Ohio shales	705
Corniferous and Upper Silurian limestones	895
Niagara shales	90
Clinton reached at.....	2,125
Red rock	18
Shale and sand	20
Red rock	50
Hard sand	15
Medina shales at	2,275
Hudson River shales at	2,475
Well finished probably in Utica shale	3,200

The shales called Niagara probably form part of the Clinton series. This will be made clear by examining the well records in the chapter devoted to the Clinton rock natural gas fields.

The lower formations were barren, but the Lower Helderberg limestones contained much salt-water. The only valuable product was gas in the Ohio shales. The rock pressure of this was 185 pounds and the daily production 78,000 cubic feet. This fuel was used under the boilers of the waterworks. Three or four years later a well was drilled on the farm of Samuel Ewalt, one mile west of the city. This is reported to have reached a depth exceeding 3,000 feet with results similar to those of the preceding one. In 1901 two wells were drilled near the city waterworks with the hope of securing fuel for its boilers. The depth reached was about 900 feet, and a small supply of gas was found.

Within the past few years a number of wells have been drilled in the valley of the Kokosing in the eastern part of the county. The first of these, located on land of E. and A. Rightmire, drilled in 1899, found the Berea at 575 feet. This sand made a show of gas, and drilling continued about 400 feet deeper in the Bedford and Ohio shales, but these were dry. Six wells have been sunk on the Stricker farm in the same neighborhood. The Berea was drilled through and produced sufficient oil to warrant pumping. This was found unprofitable, however, and in less than a year the wells were abandoned. A well or two have also been drilled on the Smethe farm in the same locality, with results similar to those on the adjacent farms. About 1899 Peter Neff drilled several wells in the vicinity of his old lamp-black factory, but these were failures.¹

In 1900-1 a number of wells were drilled in Union and Butler townships. Twelve were on the John Hammond farm, three only of which were producing in September, 1901. When first drilled these made from 100,000 to 500,000 cubic feet of gas per day, but the decline has been rapid. On the Butler, Buffington and Welker farms which are in the same neigh-

¹See page 291.

borhood as the Hammond, a half dozen wells have been drilled with results similar to those just mentioned. In this field the Berea, which is the producing sand, varies from 5 to 60 feet in thickness. Gas is found in the top of the sand and salt-water below. When the latter is liberated the well is ruined.

In the vicinity of the village Howard, in the township of the same name, several wells have been drilled. The first two of these date back perhaps 15 years and data are meager concerning them. It is known, however, that they were never pumped. Two or three years ago a well was drilled near the C. A. & C. R. R. station. The Berea, 15 feet thick, was struck at 527 feet. Some oil was found, and the well was pumped for a brief period. Three additional wells were drilled near the village with similar results.

From what has been said it is apparent that the results accomplished have not been in keeping with the time and money expended. In fact, if the story closed here the county could not be ranked among the producers of either oil or gas. Within the past three years, however, an important gas field has been developed in the southern part of the county, including parts of Miller, Milford and Morgan townships. This forms an important part of the Homer field. Apparently the limits of this territory have not yet been demonstrated, and further drilling may extend it, especially to the east. Since this gas territory has already been discussed, no further consideration will be given it here.²

WAYNE COUNTY.

About the year 1885 a test well was drilled within the corporation of Wooster. The Berea was found at 590 feet and was 65 feet thick. Work continued until a depth of 2,000 feet was reached and then the well was abandoned. It was a total failure. Not convinced by this result an old company, known as the Wooster City Milling Association, which had been dormant for 15 years, was revived and two wells drilled just west of the city. A record of one of these was as follows:¹

	Thickness of formation. Feet.	Total depth. Feet.
Drift	28	28
Sandstone and shales	207	235
Shales with thin beds of sand	215	450
Berea grit	15	465
Bedford shales, red	108	573
Ohio shales	1,232	1,805
Devonian limestone at		1,805

Neither of these wells made more than a showing of gas. These failures carried conviction and no further testing was done until 1900 when a well was sunk on the Branstetter farm along the Wooster corporation

¹*Geol. Sur. of Ohio, Vol. VI., p. 362.*

²*See page 116.*

line. This found the Berea at 465 feet and made a showing of oil, but the well was abandoned without reaching the base of this formation. In the same year a well was drilled on the Bell farm one mile south of the city. The Berea was found at 450 feet, and the Devonian limestone at 1,918. Work ceased at a depth of 1,957 feet, but the operator hoped to take up the task again with the Clinton formation as the objective stratum. In the spring of 1900 a well was drilled on the Smyser farm near Overton. The Berea was penetrated to a depth of 65 feet and then the well was abandoned, owing to the heavy flood of salt-water encountered. About the same time a well was drilled on the Jones farm three miles south of the village with results similar to those just reported.

In December, 1900, the "Dalton Oil, Gas and Mineral Company" was incorporated with a capital stock of \$10,000. The object was to test for oil, gas and other mineral products having an economic value. The first well drilled in the valley of Sugar creek in the summer of 1901, found the Berea sand at 629 feet. The formation was divided as follows:

	Feet.
Sand	35
Shale	10
Sand	30

The well was a failure. The second well was located within the corporation of Dalton, and about two miles east of No. 1. According to F. F. H. Pope, M. D., to whom the Survey is indebted for information concerning this territory, the Berea sand is found 9 feet higher in this well than in the preceding one, indicating the existence of an anticline. In the upper division of the Berea a good showing of oil was found, but when the lower stratum was tapped a heavy flow of brine was liberated and this ruined the well. Work continued to a depth of 1,500 feet with the hope of finding the Gordon or one of the deeper sands, but this was a failure. Subsequently the Berea sand was shot with 80 quarts of nitro-glycerine, but this left the well in such condition that the operators were unable to pump it, and the well was plugged and abandoned. Well No. 3 was drilled about one-half mile farther east and found the Berea at 720 feet. This was 11 feet lower with reference to sea level than well No. 2. Seven feet of pay-rock were reported in the upper division and this was shot with 40 quarts of nitro-glycerine. The result was regarded fairly satisfactory, three barrels of oil having been bailed in less than two hours. At this stage the contractor moved his tools, and the well caving, the company was not able to keep it clean, so that this too was a financial failure.

HOLMES COUNTY.

This county has not been as thoroughly tested as some others, and yet a large amount of drilling has been done. Many of the wells have made a good showing of oil or gas, and occasionally a small producer has been

secured. All, however, have soon been abandoned, and practically nothing of a pecuniary value has been secured to reward the patient operator.

Richland Township.—Between 30 and 40 years ago a well is reported to have been drilled on the Sylvanus Purdy farm. The depth was not learned. It is said to have produced a little gas, but not sufficient for any use. About 1850 a well was drilled on the Stuber farm one mile west of Purdy's, but this too was a failure. No further work was done until 1899 when four wells were drilled. One was on the William Simmons farm a mile northeast of Glenmont. The Berea sand was found, but was dry. The next well was drilled on the Zoller land adjoining the village just named. The Berea sand, 7 feet thick, made a showing only of oil and gas, and so the well was abandoned. On the farm of Daniel Jones, situated two and one-half miles east of Glenmont a well was secured which made sufficient gas for a residence. Encouraged by this success a well was drilled on the Cornell farm adjoining the Jones, but this was a total failure. The records of these have not been secured, but in all probability work did not cease until the Berea sand was penetrated.

Washington Township.—Near the village of Nashville two wells have been drilled within the past two years, one on the McMillen and the other on the Knox farms. Both were failures.

Kilbuck Township.—About 35 years ago the Millersburg Oil and Gas Company drilled a well on the Quillen farm, about two miles north of the village of Kilbuck. A depth approximating 1,000 feet was reached, but a showing only of oil and gas was secured. In 1899 a well was drilled on the Duncan farm adjoining the village just named. One hundred and ninety-eight feet of drive pipe were reported, and the Berea, 20 feet thick, was found at 642 feet. The well produced at first 5 barrels of oil per day, but the production was not maintained and pumping soon ceased. A year later a well was drilled on the Carpenter farm just east of the village. The Berea was found at 662 feet and the results were similar to those in the Duncan well. Two additional wells were drilled in the same locality in 1900. In both the Berea made a small quantity of oil, but not sufficient to warrant pumping. This territory barely missed being a small producer. With this encouragement the rocks were tested further from the village. On the Carpenter farm one mile southeast the Berea made a showing similar to the wells previously reported. A test was next made on the Lane farm one-half mile northeast of the village, but the Berea did not make as good showing as the wells at Kilbuck. In September, 1900, a well was drilled on the Christopher farm, adjoining the Lane. The sand made a showing of oil but produced considerable salt water. A well on the Stout farm one mile south of Kilbuck found the Berea at 626 feet. It made a show of both oil and gas. The drill was next moved west of the village, with the hope of better results. The well

was located on the Beller farm, and found the Berea at about 628 feet. It made a show of oil and sufficient gas for the farmer's residence. In the spring of 1901 a well was drilled on the Schneberger farm two miles south-east of Kilbuck. It made a little oil and with it some salt-water. With the exception of the Christopher well all were torpedoed with from 20 to 60 quarts of nitro-glycerine.

Hardy Township.—In 1886 a test well was drilled at Millersburg. A record of this furnished by Strome and Hull is as follows:

	Thickness of stratum. Feet.	Total depth. Feet.
Clay and rock	40	40
Blue sandstone	60	100
Slate	20	120
Conglomerate	8	128
Blue stone, soft	22	150
Rock	10	160
Blue rock	25	185
Slate	20	205
Solid rock	25	230
Slate	10	240
Solid rock	40	280
Slate, light and dark	445	725
<i>Berea sand, blue</i>	20	745
Slate, dark	140	885
Solid rock	10	895
Light slate	470	1,365
Dark and light slate	330	1,695
Sand rock	5	1,700
Light slate	10	1,710
Dark brown slate with limestone shell	70	1,780
Dark and light slate	320	2,100

The Berea made a showing of oil and gas, and was reported free from salt-water. The drill was moved to the Netherow farm 4 miles from Millersburg. This well produced some lubricating oil and has been pumped irregularly since that time. It makes gas enough also to heat and light the farmer's residence. Two additional wells were drilled in the same vicinity, but the results were less favorable.

TUSCARAWAS COUNTY.

More than 30 years ago a well was drilled on the Waddington farm about two miles north of New Philadelphia. This was the first attempt to secure oil in the county. The depth of the well was not learned. No oil was found, but the rock was charged with salt-water, and the company decided to make use of this. Accordingly a plant was erected, and from 60 to 65 barrels of salt per day are said to have been made from this well. Later other wells were drilled in the same vicinity and the locality became

for a time a salt producer of some importance. The shales above the Berea are reported to contain some gas, and an operator of experience has expressed the opinion that small but profitable wells might be secured in this.

In 1884 a well attaining a depth of 2,760 feet was drilled at Canal Dover. The record of this is given below:¹

	Feet.
Lower Coal Measures	235
Logan group	195
Cuyahoga shale	419
Berea shale (black)	11
Berea grit	26
Bedford and Ohio shales	1,874

The well head was at the horizon of the Lower Mercer limestone. The Berea contained a little gas and considerable salt-water. About the same time a Berea well was drilled along the canal about two miles south of New Philadelphia on land of Daniel Corns. Considerable salt-water but neither oil nor gas was secured. The prevalence of brine in this part of the county shows that the rocks lie quite flat, or in other words that the relief necessary for the accumulation of oil and gas is wanting.

Warren Township—Several wells have recently been drilled near Cumberland. All are reported to have reached the Berea sand, but made nothing better than a show of oil and gas.

Oxford Township—Two wells have been drilled near Post Boy, one some years ago and the other within the past year. Both went through the Berea grit, and the last one 200 feet perhaps into the underlying shales. Each made a showing of oil and gas.

Washington Township—Several wells have been drilled near the village of Gilmore. The first one was on the Lanning farm and was sunk about 12 years ago. The Berea, which was found at about 1,200 feet, contained some heavy oil which was bailed from the well for a time and used as a lubricator. A small quantity of gas still flows from the well, but no use has ever been made of it. In 1889 a well was drilled by the Port Washington Oil and Gas Company two and one-half miles southwest of the village on the Murphy farm. The Berea was reported absent, and hence nothing was secured. In the following year a well was drilled on the Kail farm one and one-half miles east of Gilmore. The Berea here made a showing of oil and with it considerable salt-water. In the winter of 1900-01 a well was drilled on the Parker farm one mile northeast of the village. The Berea was found but contained a show only of oil.

Salem Township—Early in 1899 the Port Washington Oil and Gas Company was incorporated with a capital stock of \$6,000. The object was to test the rocks in that locality with the hope of finding a large supply of oil or gas. The first well was located on the Brenner farm, and was begun May 5th. The record of this was as follows:

¹*Geol. Sur. of Ohio, Vol. VI., p. 369.*

	Feet.
Clay and mud.....	85
Salt sand	237-275
Big Injun sand.....	320-483
Berea grit	868-947
Shales	947-1509

The reported thickness of the Berea is unusually large. It contained a little oil and gas, the latter making a flame 8 feet high. No use was made of either product, owing to the small quantity, and the well was abandoned.

The second well was begun June 1, 1899, and was located on the Welsch farm one mile southeast of the village. The Berea was found at a depth of 1,013 feet and was 92 feet thick. The sand produced a heavy flow of salt-water which the drillers were unable to control. The third well was drilled on the Murphy farm in Washington township, and may be found recorded there. Well No. 4 was located on the Stocker farm about three-fourths of a mile northwest of Port Washington. The Berea was reported from 10 to 12 feet only in thickness, and made a small showing of gas. The fifth and last well drilled by the company was located on the Welsch farm, a few hundred feet from the other well on that place. The first well was reported to have produced some gas in a shallow sand, and the second well was drilled to that formation, but it contained neither oil nor gas.

Warwick Township.—In 1900 a well was drilled on the Anderson farm one and one-half miles west of Tuscarawas. The sand made a show only of oil.

Lawrence Township.—Within the past few years a number of wells have been drilled near Zoar. No records of these have been placed at the disposal of the Survey. All, however, were failures.

Mill Township.—A number of wells have been drilled in this township largely with the hope of finding a supply of gas for the manufacturing establishments of Dennison and Uhrichsville. About 10 years ago a well was drilled on the Carmack land near the last named town. No record of this has been secured, but the Berea sand is reported to have been found and made a show only of oil and gas. About 1896 a well was drilled on the Arthur farm near Dennison. The Berea is reported to have been passed through, and to have made a small show of gas. The depth of the well was approximately 1,400 feet. In 1899 a well was drilled on the Brown farm one-half mile north of Uhrichsville. The Berea sand, 40 feet thick, contained some oil and gas, but such a flood of brine was liberated that it ran from the top of the well. Encouraged by this well another one was drilled on the same farm, but the results simply duplicated those already given. Three wells have been drilled near the village of Newport. These were located on the Paul, Hines and Westhafer farms. Those on the last two farms were dry, but those on the Paul land produced a few barrels of heavy oil. All are reported to have reached the Berea sand.

COSHOCOTON COUNTY.

Exploration for oil and gas in this county began in 1865. In the northwestern part of the county and the adjacent part of Knox, principally in the angle made by the junction of the Mohican and Kokosing rivers, more than a dozen wells have been drilled. Gas springs were early observed in this territory, and with this encouragement a company was organized to test the rocks. The first well was drilled in 1865 on the south bank of the Kokosing river in New Castle township, Coshocoton county. At a depth approximating 600 feet a very heavy flow of gas was found. The well was left open a number of years and a great quantity of fuel was accordingly wasted. Twenty-two years later the production was measured by Dr. Orton and was found to be nearly 70,000 cubic feet per day.¹ Another well was drilled the same year just across the river from the first one. It too produced much gas. During 9 years this was allowed to escape, and then the well was properly cased and packed. In 1887 it was producing nearly 165,000 cubic feet per day. Within the ensuing 12 years 6 additional wells were drilled. In nearly every one of these oil and gas with salt-water were found, but none equalled Nos. 1 and 2 in their production of gas. The cost of this exploration is said to have been about \$85,000. Other wells have been sunk since that time, two of which drilled between 1880-1888 were good producers. Within the past few years Peter Neff drilled several wells in the same territory, but these were all failures. The old wells were put to an unique use, viz.: the manufacture of lamp-black, and for a time this was the only plant in existence in which natural gas was used for this purpose. The early history of this industry has already been given, and will not be repeated here.² Tests have been made in other parts of the county, and these will next be briefly reviewed.

Tuscarawas Township.—A well is reported to have been drilled many years ago in the village of Roscoe, and a little oil and gas found. Neither was ever used, however, owing to the small quantity. In 1886 a deep well was drilled in the valley at Coshocoton. The drift was 171 feet deep, and the Berea was found at 860 feet. It contained a little oil with salt-water. Not satisfied with this, work continued until the Ohio shales had been penetrated several hundred feet, but without success. Near the same time a well drilled on the Crawford farm one mile southwest of Roscoe, where nothing but salt-water was found. About 10 years later a well was drilled on the Haight farm one mile northwest of Roscoe. The Berea was drilled through, but made a show only of oil. In 1899 a well was drilled on land owned by John Hall. The Berea made nothing better than a show of oil. About the same time two additional wells were drilled in that locality,—one on the Gross farm which made a show of oil,

¹*Geol. Sur. of Ohio, Vol. VI., p. 342.*

²*Ibid, Vol. III., p. 340, and Vol. VI., p. 340.*

and the other on the Stockum land. The latter produced some oil and was still being pumped in August, 1901. Encouraged by this success another well was being drilled on the same farm at the time mentioned. These wells went to the Berea sand.

Lafayette Township.—Five wells have been drilled in this township within the last three years. All reached the Berea sand. The wells are as follows: One on the Noble farm 3 miles east of the Court House. This made sufficient oil to warrant pumping a short time. One on the McGuire land, drilled in 1901, was dry. One on the Burt farm made some gas, but not sufficient to be of financial importance. The well on the Wiggins farm made a show of oil.

Adams Township.—Three wells have been drilled on the Corbett farm in sections 18 and 19. The total depth reported is 1,800 feet, the Berea having been found at about 800. This well is said to have been started many years ago and to have been completed about 1886. The second well was drilled not long after. When a depth of 600 feet was reached the operators became involved in litigation, and the well was abandoned. The third well on this farm was drilled 5 or 6 years ago, and is said to have gone over 1,000 feet below the Berea. It too, was a failure, the Berea being dry, though a showing of oil was found in the shales below. Within the past two years four wells have been drilled near Bakersville P. O. Two were on the Ott farm, and two on the Fiatt. All reached the Berea sand, but all were failures.

White Eyes Township.—One well was reported in this township. It was located on the Kobel farm in lot 5, about one mile west of Avondale. The Berea sand was found dry.

Linton Township.—Two or three years ago a well was drilled in this township, probably on section 7. The Berea was found but was dry.

Franklin Township.—About 1898 a well was drilled in on the Lapp farm in section 18, but the Berea here as almost everywhere else in the county was dry.

Jefferson Township.—Several years ago a well was drilled just north of Warsaw, but the Berea sand was dry. Not satisfied with this a well was drilled on the south side of the village, but with results similar to those of the preceding well. On the Hawthorne farm near the west line of the township and close to the Walhonding river a Berea well has been drilled. This must be added to the long list of failures already recorded.

CARROLL COUNTY.

A persistent search in this county has been made for oil and gas. Everywhere the objective stratum has been the Berea sand. Frequently this has shown oil and gas but not in commercial quantities. With these products there has usually been found salt-water. The rocks of the county

appear to lack the arches or folds necessary for the gathering together of the oil or gas, and so while a small quantity of these may be found almost anywhere a large quantity exists nowhere.

Orange Township.—On the Clark farm in section 16 a Berea well is reported to have been drilled nearly 20 years ago. It made some gas, and this is said to be escaping at the present time. In the spring of 1900 a well was drilled on the Barrick farm near the west edge of Sherrods-ville. The Berea was found at about 900 feet, and contained some gas. With it, however, was salt-water, and the well was abandoned. During the following summer a Berea well was drilled on the Roby farm just north of town (Monroe township), the results being similar to those in the Barrick well. A dry hole has been drilled on the Gartell land in section 36, and one on the Holmes tract in section 35. On section 22 in the extreme south-east corner of the township, no less than 5 wells have been drilled. Of these one located on the Boreland tract made sufficient promise to warrant pumping a short time. The production, however, was not maintained and the well was abandoned. The other wells were dry.

Brown Township.—About 1899 a well was drilled on the Cunningham farm in the northwest quarter of section 13. The Berea contained sufficient oil to warrant pumping, but the production did not meet expectations and the well was abandoned. In the fall of the same year a well was drilled on the Tillett farm. A good show of oil was found, but it was overwhelmed by a strong flood of brine.

Augusta Township.—A well reaching a depth approximating 1,500 feet was drilled on the Manfull farm in 1899. It was entirely dry. Two years later a well was drilled on the Moncrief land in section 35. This made a show only of gas. Early in 1900 a well was drilled on the Wathey farm in the southeast corner of section 34. The Berea was found at 864 feet and was 54 feet thick. It was divided by a bed of shale, the lower portion being known as the "stray." After having been shot the well made a good show of oil, but trouble occurred in the company and the well was abandoned. A dry hole was drilled near this well on a small lot in section 35.

Washington Township.—In the spring of 1900 a Berea well was drilled on the Hewett farm in section 18. The Big Injun sand contained considerable salt-water, but the Berea was dry. A well has been drilled on the Carr farm, but at a depth of about 800 feet the tools became fast and the well was abandoned. About three years ago (1898) a Berea well, which was dry, was drilled on the Rowland farm in section 4. A dry hole has been drilled in the northwest corner of section 19.

Rose Township.—On the old Wadsworth farm near Magnolia a well is reported to have been drilled many years ago. It was never pumped, but the farmers skimmed the oil from the top of the well and used it in

greasing machinery. Recently a well was drilled near this one, but the Berea made nothing better than a show of oil.

Center Township.—In 1899 a well was drilled on the Lotz farm. The Big Injun sand contained much salt-water, and the Berea made a smell of oil. In the same year a well was drilled on the Buck farm, but the Berea did not make even a show of oil.

Union Township.—About the year 1895 a well was drilled on the C. F. Brooks farm in section 6, the depth having been reported at 1,500 feet. No oil was found in the Berea, but a small quantity was secured in a shallow sand. On the J. H. Brooks farm in section 12 a well was drilled to the shallow sand just referred to, but nothing better than a small quantity of black oil was found. On the T. F. Brooks farm in section 5, a hole was drilled to the shallow sand, and a small quantity of dark oil secured. This was pumped a short time. In the spring of 1899 a well was drilled on the Gantz farm in section 6. The Berea sand was 56 feet thick, and after having been shot with 50 quarts of nitro-glycerine produced two barrels of oil per day. The well was soon abandoned. About the same time a Berea well was drilled on the John Fawcett farm. It made a show of oil, but was abandoned without having been shot. A well is reported to have been drilled to a depth of 2,000 feet on the John Sell farm in section 9 in search of the Gordon sand, but without success. A large quantity of salt-water was secured. In 1900 a Berea well was drilled on the Kahl farm in section 3. The well was shot and made some oil, but was not pumped. Notwithstanding this long list of failures a well was being drilled on the J. G. Brooks farm in 1901.

Lee Township.—In 1899 a Berea well was drilled on the farm of T. R. Taylor in section 22. Considerable gas and a show of oil were secured in the Big Injun and a show of oil in the Berea also. The well was never shot. Other dry wells in the township are as follows: One on the J. and G. Nohle farm in section 3; one making a little oil on the McEntire farm in section 2; one on the McConnell farm in section 34; one on the B. Noble farm in section 26; one on the Allen land in section 28.

Loudon Township.—On the John Scarlett farm in section 20 a Berea well was drilled in 1900. The sand was of good quality and produced some oil. In the same year a well was drilled on the R. Gibson farm in section 32. The sand made the usual show of oil and gas, but the well was abandoned without having been shot. In 1901 a well was drilled on the T. A. Stenger farm in section 31, and produced considerable gas, but this well also was abandoned without having been shot. On the Long farm in section 19 four wells have been drilled, one only of which was dry. The Berea was found at from 1,100 to 1,200 feet, and was from 30 to 40 feet in thickness. The producing wells made from three to four barrels per day. There is no pipe line in the field, and in 1901 the wells were

quiet owing to the lack of market for the oil. Just across the line in Jefferson county several wells have been drilled. The field is known as the Amsterdam. From the dry holes already drilled it seems safe to say that the territory will not become important.

Fox Township.—About 10 years ago a well was drilled on the Queen farm in section 11. The Berea sand contained a small quantity of salt water, but neither oil nor gas. On land of Frank Cummings in section 33 a deep well was drilled a number of years ago. The Berea sand is reported to have been reached and to have made a show of oil. About the year 1896 a well was drilled on the Allison farm in section 33. The Berea sand is reported 60 feet thick. After having been shot the well made a showing only of oil. About 6 months later a well was drilled on land of T. G. Donaldson in the same section. The sand there was hard and dry. A dry hole has been drilled on the George farm in section 28.

Monroe Township.—A Berea well was drilled on the Dutenhaver farm in section 35 in 1899. The sand made a show of oil, but the well was abandoned without having been shot. Dry holes have been drilled on the Suter farm in section 11, and the Roby farm in section 8. In August, 1901, a well was being drilled on the Davis land in section 20.

Harrison Township.—But one deep well was reported in this township, and this was dry. The well was located on the Lotz farm in section 8.

Perry Township.—Two dry holes were reported in this township, one on the Palmer farm in section 6, and the other on the Scott farm in section 17.

SUMMIT COUNTY.

A large number of wells have been drilled in this county. Some stopped at the Berea, but others continued until the great limestone below had been penetrated. The earliest of these wells, located at Akron, found the Berea grit at 260 feet and the Corniferous limestone at 2,125, making the interval between the two 1,862 feet. Work continued until the limestone had been drilled to a depth of 335 feet. The well was a total failure as far as oil and gas were concerned.¹

About 20 years ago several wells were drilled near Clinton in the southwestern corner of the county in search of a reported coal seam, but without success. The Berea grit was found, but was barren of oil or gas.

Within the last few years a number of deep wells have been drilled in the vicinity of Barberton in search of salt. Below is a record of well No. 1 of the Columbia Chemical Company, at Barberton:

¹*Geol. Sur. of Ohio, Vol. VI., pp. 357-9.*

	Thickness of stratum. Feet.	Depth to bottom of stratum. Feet.
Sand, very soft	40	40
Gravel, very soft	20	60
Quick-sand	30	90
Slate, black, soft	45	135
Sand, black, soft	15	150
Cuyahoga and Sunbury (Berea) shales	310	460
Berea grit, dark	10	470
650 feet of 8¼ inch casing.		
Bedford and Ohio shales	1,710	2,180
Corniferous limestone top at		2,180
Lime, brown, very hard	60	2,240
Lime, gray, very hard	80	2,320
Lime, white	150	2,470
Lime, gray	30	2,500
Sand, brown, very hard	30	2,530
2,582 feet of casing.		
Lime	244	2,774
Rock salt	30	2,804
Lime	16	2,820
Rock salt	5	2,825
Lime	5	2,830
Rock salt	69	2,899
Lime	107	3,006

The wells usually make a show of gas at about 2,500 feet. This appears to be from the same horizon as the gas at Jefferson, Ashtabula county. These wells demonstrate that neither oil nor gas may be expected in the northern half of the county.

About 15 years ago a deep well was drilled near Peninsula in the northern part of the county. Gas was secured from the Ohio shales, and this is reported to have supplied a residence since that time. Later a half-dozen wells were drilled to the same horizon, with similar results. One well lighted the streets and about 10 residences for a short time, but the flow soon became inadequate. The best well now (1902) does not supply more than two residences.

A well having a depth of about 800 feet, was drilled in Northfield township in the northern part of the county in 1902. The Berea encouraged the operators, and they were planning a number of wells, hoping in this manner to secure a profitable supply.

STARK COUNTY.

As might be expected a county with such extensive manufacturing interests as Stark's would not rest content until a thorough test had been made of the underlying strata for natural gas. The result has been the discovery of two small reservoirs of the desired fuel, but the supply has not been at all in proportion to the energy and money expended.

In 1886 the Canton Steel Company drilled a well at Canton, reaching a depth of 2,200 feet, a record of which is given below:

	Thickness of formation. Feet.	Total depth. Feet.
Drift	17	17
Coal (No. 3 seam).....	1	18
Slate and sandstone	43	61
Coal (No. 2 seam).....	streak	61
Fire-clay, slate and sandstone	39	100
Sandstone	49	149
Slate	14	163
Coal (No. 1 seam).....	streak	163
Fireclay and slate with thin beds of sand stone	112	275
Logan conglomerate (Big Injun).....	140	415
Cuyahoga shale	260	675
Berea grit	80	755
Bedford shale, dark red	17	772
Total depth		2220
Ohio shale	1,448	2220

The elevation of the well head is about 1,030 feet above tide. At a depth of 110 feet so large a pool of water was found that it ran from the well. The Berea contained much salt-water, but neither oil nor gas. The base of the Ohio shales was not reached.

In 1887 another deep well was drilled in Canton. This was located near the intersection of Fourth street and East creek and was drilled by the Canton Oil, Gas and Coal Company. A large quantity of salt-water was found in a sand rock at a depth of 750 feet, and this formation was doubtless the Berea grit. The well was cased at a depth of 800 feet. From that point to a depth of 2,800 feet nothing but shales were found, and these were entirely dry. The total depth was reported at 3,250 feet. An unsuccessful effort was made to use a brine found at 2,800 feet for the manufacture of bromine.

In the fall and early winter of 1885 a deep well was drilled on the land of the Russell Manufacturing Company at Massillon. A record of this well has been furnished the Survey by an officer of that company, and is as follows:

	Thickness of stratum. Feet.	Total depth. Feet.
Sand and gravel	145	145
Conglomerate sand rock	40	185
Cuyahoga shale	425	610
Berea sand	45	655
Bedford flag rock	35	690
Ohio shales	1,825	2,515
Corniferous limestone	32	2,547

The Berea produced considerable gas, but it was soon overwhelmed by a flood of salt-water that flowed from the same stratum. Not long afterwards another well was drilled at the rolling mill in the northwest quarter of the town, but such a heavy flow of salt-water was found in the Berea that the well was abandoned. Other deep wells were drilled in or near the city years ago, but no specific data concerning them were secured. One thing, however, is certain, none were important producers of either oil or gas. In 1898 a Berea well making a show of oil was drilled on the land of H. H. Everhart about two miles west of Massillon. In 1900 a well was drilled on the land of George Snyder two and one-half miles east of Massillon. When the Berea sand was penetrated much salt-water was liberated, but there was no oil and but little gas. The well was not shot.

A number of deep wells have been drilled in Alliance and vicinity.¹ One is reported to have been drilled in the north part of town about 15 years ago and to have reached a depth of 2,800 feet, but it was dry. In 1900 a well, located on the Grove farm 5 miles east of Alliance, reached a depth of 1,500 feet, and so went far below the Berea, but it too was a failure. In the spring of 1900 a well was drilled on the Marchamb lot in Alliance, and reached the Berea at 640 feet. The rock was charged with gas, the closed pressure being 200 pounds per square inch, and the daily production 1,500,000 cubic feet. A well located 1,000 feet farther south was soon begun, and the rock pressure was similar to the preceding one, but the production was 2,500,000 cubic feet per day. The third well was located on the Bates lot lying 3,000 feet southeast of the last well. This produced 3,500,000 cubic feet per day. The largest well in the field was drilled late in the winter of 1900 on the Emery Miller lot, by the Morgan Engineering Company. It had a closed pressure of 200 pounds per square inch, and is reported to have produced at the rate of 5,000,000 cubic feet per day. In all about 20 wells have been drilled in this vicinity. These are very short lived, ordinarily not exceeding 3 months, and the best not lasting longer than 6 months. The great well of the Morgan Engineering Company lasted 3 months only. The wells are located along a northeast and southwest line. The producing sand in all cases is the Berea. In well No. 4 of the Transue and Williams Company, the formation was as follows:

	Feet.
Sand	44
Shale	4
Sand	86

The gas is found either in the bed of shale or in the top of the underlying sand. On drilling deeper a reservoir of salt-water is liberated. The field has been used very largely by the local manufactories, and in December, 1900, a line was laid through the town by the Eureka Oil and Gas

¹Data by Mr. O. F. Transue.

Company, and families were supplied at the rate of 25 cents per thousand cubic feet. By August, 1901, the supply became so small that the demand could not be met.

Paris Township.—Four wells have been drilled in this township, one on the land of N. Stonehill and another on land of G. J. Geszner. Each made a showing of oil. One of these was drilled in 1897 and the other in 1901. In the latter year a well was drilled on the farm of Andrew Sponseller located one mile north of Myers. The Berea was found at 745 feet and had a thickness of 52 feet. It made a faint showing of gas. In the spring of 1900 a well was drilled on the Metz farm in section 2, but work stopped with a shallow sand, called Big Injun, by the driller.

Osnaburg Township.—About the year 1899 a well was drilled on the Wolf farm near Robertsville. The Berea sand was found at 680 feet, and after having been shot with 70 quarts of nitro-glycerine, made a very light flow of gas. The well was abandoned.

Washington Township.—In December, 1900, a well was drilled on the Hawkins farm in section 36. The Big Injun was reported at 420 feet, and contained much gas, but the well was ruined by salt-water. On the Miller farm, joining the Hawkins, a Berea well was drilled. The sand was reported at about 800 feet, but was dry.

Nimishillen Township.—Nearly 10 years ago a well was drilled at Lewisville, and reached a depth reported at 825 feet. A small flow of gas was found but was soon drowned by salt-water. In the summer of 1901 two wells were drilled on land of Henry Bixler in the extreme northwest corner of the township. The Berea sand having a thickness of 30 feet, was found at 660 feet. Each well produced gas, one having a closed pressure of 210 pounds and the other of 175.

Marlborough Township.—In the southwest corner of this township a few wells have been drilled. The territory is continuous to the Bixler property just mentioned. The Berea sand is about 30 feet thick, and the rock pressure 210 pounds. All the wells in this field were drilled by the Diamond Portland Cement Company which uses the fuel in its boilers and kilns. The company pays \$200.00 per year to the land holder for each producing well.

MAHONING COUNTY.

Drilling in this county, while abundant to show the barrenness of the Berea grit and the underlying Ohio shales, has nevertheless been much less extensive than in the counties farther south. About 1866 or 1867 a well was drilled at Brier Hill, and reached a depth approximating 500 feet. Gas and oil were found at a reported depth of 420 feet, but not in paying quantities. The prominence of the iron industry at the county seat and the value of gas as a fuel in this business secured a more thorough test, and in 1875 a well was drilled to a depth of 2,480 feet at the Valley

Mill, Youngstown. The Berea grit was passed through at 200 feet, and from that depth to the bottom of the well the work was in shales and even then the base of the formation was not reached.¹ At Hazelton a few miles southeast of Youngstown, a well was drilled in 1886. In this gas was found in both the Berea sand and shales above, but the well was ruined by salt-water. The Berea grit attained a thickness of 160 feet in this well, a figure much in excess of other measurements in that part of the state. In the same year a well was drilled on the Reywight farm, 3 miles southwest of Youngstown. The Berea sand was found at 435 and had a thickness of 50 feet. Work did not cease until a depth of 2,075 feet was reached, but this did not find the base of the shales. Neither oil nor gas in commercial quantities was found.

In the summer of 1900 a well was drilled on the Creed farm a mile or less west of the corporate limits. The Berea was reported to have been found at a depth of 200 feet, and to have made a show of oil. Not until 300 feet of the shales underlying the Berea were passed through did work cease. In the same year a well having a depth of 600 feet was drilled near the village of Canfield, but made a show only of oil. In 1893 a well having a reported depth of 1,800 feet was drilled at Lowellville, near the Pennsylvania line, but it produced neither oil nor gas. About the year 1894 several Berea wells, having a depth approximating 400 feet, were drilled near West Austintown, and yielded a small quantity of heavy oil which was bailed from the well for a short time.

TRUMBULL COUNTY.

This county ranks as one of the pioneer producers of oil in this country. In the spring of 1860 a well having a depth of about 60 feet was drilled at West Mecca. Oil was secured at 45 feet, and the production being considerable and the market small, a large supply soon accumulated. In the same spring two wells were drilled one mile south of the hamlet named; one, located on land of James Cowdery, is said to have produced 40 barrels per day, and to have been long lived though the production was at a diminishing rate. The second well was drilled on an adjoining farm and this too was a good producer. In both the pay-rock was found at about 50 feet. Another well was drilled in the same year on the Cowdery farm referred to above, but this one is reported to have been smaller, producing from 10 to 12 barrels per day. Besides, this well was short lived, having been abandoned about 1862. The wells on the Cowdery and adjacent farms were located because of so-called surface indications, consisting of a thin scum of oil on pools of water and occasionally on brooks.

The success of these wells attracted attention outside of the community and soon oil men in large numbers were drilling in the field. The production increased rapidly, and soon became a drug on the market. One

¹*Geol. Sur. of Ohio, Vol. VI., p. 402.*

man hauled many barrels to Warren 12 miles distant, where it was finally sold for storage. Refineries were built that used not only the local production, but also some from Oil Creek, which was hauled in wagons. The refineries, however, were short lived and so played a small part in the history of the field. Work was brought practically to a standstill in 1861 by the opening of the civil war, many of the drillers abandoning their machines and entering the army.

Sometime between 1861-5 an attempt was made to secure the oil in an unique way; this consisted of shafts and tunnels. Three of the former were sunk, and when the Berea grit had been penetrated a few feet, tunneling began. To the east a small valley existed, and the plan was to extend the tunnel until it intersected the valley. Then it was expected that the oil would flow from the rock through the tunnel. The plan, however, was never completed. About 20 years later another attempt was made at tunnel construction. A shaft was sunk to a depth of 52 feet, and a tunnel was excavated from this 32 feet to the east and 30 to the west. After spending a small fortune in the foolish enterprise it was abandoned.

Soon after the close of the war work was renewed, and drilling became quite active. The neighboring townships of Mesopotamia, Bristol and Green were tested, the result being a few producing wells in each. The oil was a lubricator and most of it was shipped to Pittsburg, Cleveland and adjacent places. It commanded usually from 60 to 75 cents per gallon, but the price is reported to have risen to \$1.25.

About the year 1878 active drilling in the field began for the third time, and tests were made in the surrounding townships, but the excitement lasted a few months only and then the drillers left the field. Much of the territory had been drilled before, and consequently the wells were small. Since that time an occasional well has been drilled. The Cowdery farm is still the best producer, but even here none of the wells are pumped regularly.

The early wells were drilled wholly by spring-pole. Instead of derricks three poles were set up. About 1870 steam began to be used, but the power was simply attached to the spring-pole. When drilling in the field began for the third time more modern methods were introduced. Derricks from 30 to 40 feet high were constructed, and the tools and power such as might have been found in other shallow territory at that time. By such methods a well could be drilled in two days of 12 hours each.

The oil is derived from the Berea grit which lies immediately below the glacial drift. **At West Mecca the formation is 80 feet thick, and consists of beds of sand with an occasional intercalated bed of shale.** Near Mecca two pay-rocks are found, one at 30 feet, and the other at about twice that depth. The lower sand is the larger producer, and the quality of oil is said to be similar in the two. The wells are not cased; the water being excluded by the primitive seed-bag, which served so useful a purpose in

the sixties. A number of wells were shot with gunpowder, but the results were not beneficial. The oil has a gravity of 26 degrees B., and bears an excellent name as a lubricator. It is safe to say that the life of the field is near the close. In fact the production during many years past has been so small that in a commercial way it might pass unnoticed. In the summer of 1901 the oil retailed at 40 cents per gallon, but considerable of a reduction was made when purchased by the barrel. No difficulty has been found in disposing of the product.

A number of deep wells are reported in the field; on the Foapes farm one mile east of West Mecca a well having a depth reported at 1,100 feet was drilled sometime between 1860 and 1870, and a flood of water, which still runs from the hole, was found. A well having a depth of 1,300 feet is said to have been drilled on the Cowdery farm about 1864; the deepest well in the territory was drilled on the Klump farm, three-fourths of a mile south of West Mecca, somewhere between 1880 and 1890, and reached a depth of 2,300 feet, but like the other deep wells just mentioned was a failure. In 1864 a well was drilled at Niles in the southern part of the county, and a heavy flow of gas was reported at 640 feet, but the drill was kept at work until a depth of 900 feet was reached, but the well was soon abandoned. Later another one was drilled in the same vicinity, but at a depth of 780 feet the tools became fast and work ceased.¹ In 1900-1 a well was drilled at Brookfield in the southeast corner of the county. It is reported to have reached a depth of 1,800 feet, but was dry.

ASHTABULA COUNTY.²

The Ohio shales, which everywhere underlie the county, and form the surface formation of nearly the whole of it, contain natural gas in large quantities, but unfortunately the product is so diffused that it cannot ordinarily be secured in commercial quantities. In other words the production of a comparatively large area is not confined in a small one, as in the well known oil and gas fields in other parts of the state. Many wells have been drilled in the county, especially in the northern part around the towns along the lake shore. At Conneaut, in the extreme northeastern corner, one reached a depth of 1,942 feet, passing through the shales and entering the underlying limestones, but a strong brine only was secured. Other wells drilled near the village yield some gas, but not enough to make the territory valuable. At North Kingsville a well reached a depth of 1,200 feet without finding the base of the shales. No gas was found below 372 feet, but small reservoirs were found at several horizons above that plane. A number of wells have been drilled at Ashtabula, and several have yielded a small supply of gas, each sufficient to meet the wants of a residence. The supply is derived from comparatively superficial depths, usually less than 500 feet. Several wells have been drilled in and around Geneva, in the

¹*Geol. Sur. of Ohio, Vol VI., p. 401.*

²*This territory does not form part of the Carboniferous, but it is not sufficiently important to warrant a separate chapter.*

northwestern corner of the county with more than ordinary success. The gas has been found at depths ranging from 130 feet or less down to 1,400, and is used for fuel and light by those citizens fortunate enough to possess it.¹ Many of these wells were drilled 20 years ago, but more recently a number have been drilled in other parts of the county, and several have passed entirely through the shales into the great limestones below; one on the Hayes farm in Cherry township, drilled about 1897, is reported to have attained the great depth of 2,775 feet, but no information has been secured as to the strata passed through, and the depth given may not be correct. The well was a failure. In 1899 a well was drilled by the Jefferson Oil & Gas Company on a lot owned by J. A. Giddings, situated within the corporate limits of Jefferson. A record of this furnished by F. S. Jones, is as follows:

	Feet.
Black slate (Ohio shale).....	1,810
Light colored limestone	288
"Gas sand," thin	
White sand, called "salt sand"	13
Gray rock	8
Black rock	8
Oil sand	13

This well produced 7 barrels of oil the first hour and then dropped suddenly to one and one-half barrels per day. Not long afterwards a well was drilled near this one with similar results. The oil has a gravity of 43 degrees B. These are the only oil wells secured thus far (1901) in the county.

In the spring of 1900 a well was drilled on land of George Hunter, two mile northwest of Jefferson. The base of the shale was found at 1,692 feet, and the "gas sand" at 1,989. The well yielded considerable gas, the closed pressure rising to 830 pounds per square inch. Since that time nine additional wells have been drilled in that locality, and all contained gas. According to F. S. Jones the closed pressure in these has in some cases exceeded 800 pounds per square inch. The daily production of the best wells has been about 2,500,000 cubic feet. As developed in 1901 the field has a length of three miles and a width of one. Its direction is north-east and southwest.

The sand has a thickness ranging from 30 to 40 feet. Gas is found in the very top, and just below lies a large reservoir of salt-water, which is constantly threatening the life of the wells. The Northeastern Oil and Gas Company has control of the territory, and supplies fuel to Jefferson, Ash-tabula, Geneva and Conneaut.

In the fall of 1900 a well was drilled on the Traverse farm, two miles north of Jefferson, but a showing only of gas was secured. Outside of the localities mentioned a few deep wells have been drilled. One on the

¹*Geol. Sur. of Ohio, Vol. VI., pp. 422-27.*

Strong farm in the southwest corner of Jefferson township reached a depth of 2,240 feet, but was dry. One on the Bancroft farm near Eagleville, found a heavy deposit of salt-water and so was abandoned. In the southern part of Plymouth township a well has been drilled on the Van Aken farm, but this was entirely dry.

A number of samples of drillings from below the Ohio shales have been provided the Survey for examination. These from the top of the Devonian limestone have a gray color and contain many fragments of fossils. A sample taken 25 feet lower had similar characters. Both effervesced freely with cold hydrochloric acid. The "gas sand" is composed almost wholly of quartz. It contains many fossil remains, especially Favosites or closely related forms. The "Salt sand" which lies immediately below has a light gray color. It consists of quartz with a little lime, the latter probably acting as a cement. The oil sand is much like the above.

From what has been said it is seen that the oil, gas, and salt rocks are sandstones lying about 300 feet below the base of the Ohio shales. This is the place of the Lower Helderberg limestone and the formation in question doubtless is of similar age. Similar beds of sand have been found in the Lower Helderberg in other parts of Ohio and adjacent states. Good examples are found at Monclova and Sylvania, in Lucas county, where the rock is of such quality that it has been used quite extensively in glass manufacture. Another good exposure is found in Wood county, where it is known as the Grand Rapids sandstone. Dr. Orton has expressed the opinion that the formation which is the source of the brines that supply the great salt works at Cleveland, Wadsworth and other points in the northeast corner of the state is probably the equivalent of the sandstones just mentioned.¹ Those of Ashtabula county occupy a similar position.

GEAUGA COUNTY.

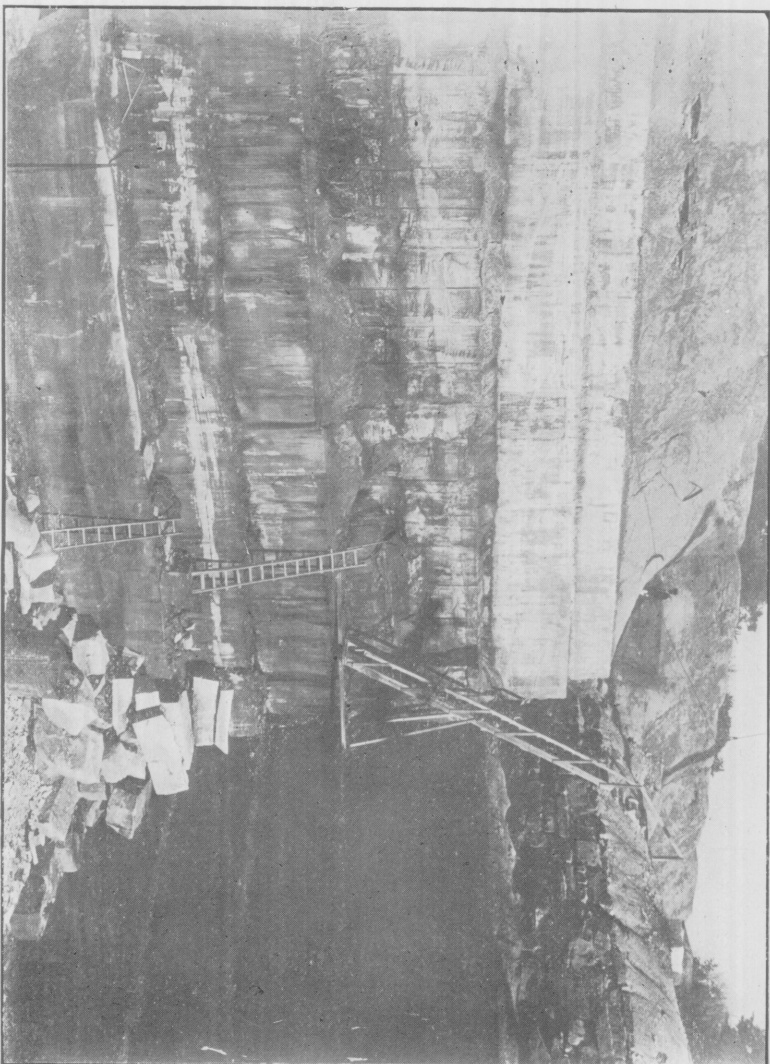
The surface formation in this county belongs in part to the Coal Measures, in part to the Lower Carboniferous and in part to the Ohio shales. The Pottsville conglomerate is prominent, forming in places a conspicuous escarpment.

A number of deep wells have been drilled, but the records have become scattered or lost, and consequently it has been impossible to secure accurate data. In 1899 a well was drilled on the Kiser farm near Hampden. According to report a depth of 2,472 feet was reached; the Berea was found at 175 feet and the Carboniferous limestone at 2,000. Nothing more than a show of oil was reported. In the summer of 1902 a well was drilled on a neighboring farm owned by Mrs. Huntoon. No report has been received of the result.

About the year 1888 a well was drilled on the Hovey farm in Munson township. The depth reached is reported at 1,500 feet. Some gas was

¹*Geol. Sur. of Ohio, Vol. VII., pp. 17-18.*

PLATE VI



THE BEREA GRIT AT BEREA

found in the Ohio shales, but the quantity was of no value, and the well must be recorded with the failures.

Preparations were being made in 1902 to drill additional deep wells in the county, the objective stratum being the Jefferson gas rock, which has elsewhere been shown to belong to the Lower Helderberg.

LORAIN COUNTY.

The Berea grit forms the surface rock of the greater part of this county. Oil was discovered in the formation about 1860. The test well is said to have been drilled because of the usual surface indications. At a depth of about 65 feet a heavy oil was found, but the quantity was so small that it produced little or no excitement.

No further work is reported for 15 years, when another well was drilled on the same farm. This is said to have been a relatively large producer. The oil proved to be a good lubricator, and found a ready market in Cleveland and adjacent places. This well produced considerable excitement, some farms selling for four times their previous value. The excitement lasted two or three years, but there was some drilling as late as 1880. A few of the wells are reported to have started as high as 100 barrels per day, but the decline was rapid. Several of these wells are still pumped occasionally. Within the past few years a number of additional wells have been drilled in this territory, but the results have been disappointing. The field is commonly known as the Belden.

Near Ehart, in the southwestern corner of the county, several Berea wells have been drilled within the past few years. A small quantity of oil was found, and the wells were pumped for a short time, but the results were not commensurate with the energy and money expended.

MEDINA COUNTY.

Around the village Lodi, in the southern part of the county, a small oil field has been developed. The territory extends nearly due north and south, and has a length of about three and one-half miles, and a maximum width of about one mile. It includes parts of Harrisville and Chatham townships.

The first successful well is reported to have been drilled in 1899, on the farm of F. R. Shaw, near the south line of Chatham township. From that point holes were drilled in all directions, and at one time five strings of tools were kept busy, the field experiencing a small boom. In 1902 all was quiet, but doubtless other wells will yet be drilled.

The best wells had an initial production of from 40 to 60 barrels per day, but as in all shallow territory the decline was rapid. The oil is dark and of about 39 degrees B. gravity. In July, 1902, the number of producing wells was about 70.

The sand is the Berea, and is found in the valleys at about 260 feet. The maximum thickness reported is 110 feet. In the spring of 1901 the Buckeye Pipe Line Company laid a line connecting their tanks with the railroad, shipping the oil in tank cars; but when the Lodi refinery began work in December of the same year, the Buckeye Company removed its line.

The refinery to which reference has just been made has one still of about 250 barrels capacity. The company relies for its crude material on the wells around Lodi. There is no other supply near. During the summer of 1902 it did not use the small production of this field, and in consequence the producers were asking the Buckeye Pipe Line Company to come again to their rescue.

A well having a reported depth of 1,670 feet is said to have been drilled in the vicinity of Lodi about the year 1888. According to the information received the Berea grit was struck at approximately 260 feet and the Corniferous limestone at 1,600.

Just west of the Lodi field great depths of drift are reported. One well found 340 feet, the first formation struck having been the red Bedford shales. Such depths denote important drainage changes, the old valleys having been filled with drift during the glacial period.

A number of tests have been made in other parts of the county for oil or gas. Three deep wells are said to have been drilled in the vicinity of Medina, but all failed to secure the coveted material. The Berea has been tested at a number of places in Lafayette and Montville townships, but without favorable results. In Litchfield township, near the Lorain county line, several small gas wells have been secured. The farmers occasionally secure a supply to heat and light a residence. This territory is close to the Belden oil field, lying in Lorain county.

In the southeast corner of the county a number of wells have been drilled for salt. These are at or near Wadsworth. Doubtless the formations correspond closely with those in Summit county, records of which are given elsewhere.

CHAPTER V.

ORIGIN OF OIL AND GAS, AND THE GEOLOGICAL CONDITIONS UNDER WHICH THEY ARE FOUND.

I. ORIGIN OF OIL AND GAS.

Few questions relating to Economic Geology are more generally asked than that of the origin of oil and gas, and few are more difficult to answer. In fact it is impossible to state with certainty at the present time how these fuels have been formed. Nevertheless, because of the great interest, the subject will be reviewed here.

Petroleum and natural gas are intimately associated. Wherever oil is secured there gas also is found, and as is well known, it is the expansive force of the gas which produces flowing wells. As the gas escapes the force weakens and the well ceases flowing. Generally where natural gas is found in large quantity oil also exists, or is near. This is often well illustrated on anticlines, gas being found at or near the summit of the arch and oil farther down the slope. However, oil is not always associated with gas. Thus the great gas fields of central Ohio are not associated directly or indirectly with oil. In fact the Clinton formation has nowhere been proven to be an important producer of oil. As has already been reported in this volume, a small pool of oil has been found in the Clinton in the northern part of Vinton county and one well has been secured in this formation in Perry county, but these wells are many miles from the gas field. In the Homer field oil is still more conspicuously absent, no wells having yet been reported. Examples of a similar nature might be cited from other parts of Ohio and also from additional states, and so it may be regarded as certain that petroleum is not a necessary accompaniment of natural gas.

Considered from the chemical standpoint oil and gas are closely related, and where the oil has an unusual composition the gas of the same field is likely to be characterized in a similar manner. An illustration of this is found in the oil and gas of the Trenton limestone fields where the sulphur which is so striking a constituent of the oil is found in the gas also. In those fields where sulphur is not found in the oil it has not been reported in the gas.

From the intimate association of oil and gas in nature and from their chemical relations it seems certain that both have been derived from the

same substances and probably in the same general manner. For these reasons the two will be considered together in this chapter.

Of the theories propounded that have received serious consideration, two classes may be recognized:

First those which assign to these products an inorganic origin. These maintain that oil and gas have been produced by the reactions of inorganic substances. In general it may be stated that this class of theories has been advocated by chemists, and at the present time some eminent scholars contend that this is the most reasonable view to take of the subject. This class might be called the chemical.

The second class of theories assigns an organic origin. That is, that oil and gas have been formed in some manner from organic matter, either animal or vegetable or both. As to how the changes have been produced, however, there is much difference of opinion. While this class has been advanced by some chemists, it has been most strongly advocated by geologists, and might well be called the geological. These theories will now be considered with some detail.

THE INORGANIC OR CHEMICAL THEORIES.

While many theories have been propounded that fall in this class, a few only need be considered here. In 1866 Bertholet, a distinguished French chemist, argued that petroleum has been produced by the action of water containing carbonic acid on alkali metals deeply buried in the earth and hence highly heated. He appears to have adopted Daubree's hypothesis that the earth contains in its interior large quantities of these metals, especially sodium and potassium. He found by experiment that when carbonic acid acts on hot alkali metals, acetylides are formed, and that these bodies when treated with vapor of water produce hydrocarbons resembling petroleum.

In 1871 Byasson presented a theory maintaining that petroleum has resulted from the action on each other of water vapor, carbonic acid, sulphuretted hydrogen and hot iron. This theory also has some support from the laboratory for Byasson claims to have obtained in this manner products resembling petroleum. The vast repositories of oil found in nature, he thought, were produced by sea water containing carbonic acid or limestone in solution percolating deep into the earth and then acting on metallic iron or iron sulphide.

The inorganic theories were strengthened in 1877 by Mendeleeff, one of the most distinguished chemists of the day. He argued that the interior of the earth contains metallic carbides, that is metals, especially iron combined with carbon. Water coming in contact with these highly heated carbides would, he claimed, start reactions which would produce hydrocarbons, and convert the metals into oxides. This theory also is supported by laboratory experiments. The manufacture artificially of acetylene gas

at the present time is somewhat related to the method by which Mendelejeff thinks the great repositories of petroleum have been produced.

In the year mentioned in the last paragraph Cloez obtained hydrocarbons resembling some of the petroleum products by the action of sulphuric acid on the carbides of iron and manganese. A year later (1878) he produced a liquid resembling petroleum by the action of hot water on the carbide of manganese.

The studies of the French chemist Moissan have brought to light a large number of facts which seem to lend some support to the chemical theory of the origin of at least some of the petroleum and gas deposits. This chemist found that at very high temperatures most of the metals will combine with carbon to form substances called carbides. The most familiar one of these is calcium carbide, which is manufactured on the large scale for the production of acetylene.

As is well known, acetylene is produced from calcium carbide by the action of water upon it. Some of the other carbides produce other hydrocarbons. Thus aluminum carbide produces pure methane when acted on by water. Others produce mixtures of hydrogen, methane, ethylene, etc., and a few yield in addition liquid hydrocarbons which closely resemble petroleum. Four kilograms of uranium carbide gave 100 cc. of liquid hydrocarbons with asphalt base.

From these experiments Moissan concludes that if the interior of the earth were to contain large amounts of carbides to which water were to find its way through cracks and fissures in the earth's crust, gas and oil would result; and the large amount of heat developed in the chemical reaction would produce a substance very similar to crude petroleum. That the interior of the earth may contain such carbides, is made to appear probable from considerations that would lead too far to discuss.

These theories may suit the chemist very well, but they fall short of meeting the demands of the geologist. In general it can be said that they have been developed without due regard for the geological conditions under which oil and gas are actually found.

The theories given appear to require one element in common, namely great heat. Now this can be secured, so far as gas and oil are concerned, in only two ways, (1) by reaching great depths in the earth's interior or (2) by intrusion of molten rock. The great oil fields of this country lie in the Mississippi basin, a region that has been singularly free from intrusions of molten material. These remarks apply equally well to the recently discovered pools along the Gulf of Mexico. It follows naturally from this that the great supplies of petroleum in the United States cannot have been produced through the agency of heat derived from intrusions of highly heated material.

The other alternative, namely that the heat was obtained at great depths, is equally inadmissible. Not that high temperatures do not exist

at such places, for all admit that such are there found. However the great pools of oil and gas lie near the surface where the temperature is not more than 60 degrees above that at the surface, allowing an increase of one degree for each 50 to 60 feet of descent. In fact important pools have been found at depths of 100 feet or even less, and it is apparent to all that the temperature at such places must be little in excess of the surface average. The evidence of the absence of heat in the oil or gas-bearing rocks in earlier times is as positive as the present. Heat is one of the principal factors in metamorphism, and if any such temperatures as the inorganic theories demand had existed, the rocks themselves would furnish unmistakable evidence. In Ohio alone probably 50,000 wells have been sunk to depths approximating 1,000 feet; many have reached 1,500 feet; a smaller number 2,500 feet, and occasionally a well has exceeded 3,000 feet. Now the drillings from these are a unit in denying any evidence of high temperatures. In fact fragments brought up from the greatest depths show no more evidence of heat than do those 100 feet or less below the surface.

From these lines of testimony it is safe to say that the rocks which now contain the oil and gas have never been highly heated. There remains but one alternative for the advocates of this class of theories, and that is oil and gas were produced at great depths and have gradually risen from that place to the position which they now occupy. To this there appears to the geologist an insuperable difficulty, for lying between these deep seated and hence highly heated rocks and those which now contain oil and gas are, in many places at least, great thicknesses of compact shales and other fine grained rocks which are impervious. This is well illustrated in southeastern Ohio where the Berea grit, and of course the rocks lying above it, and which contain important quantities of oil or gas have lying below them a great mass of fine grained shales. At Lancaster their thickness is 805 feet; at Junction City 1,174, at McConnelsville 1,739 and at the Ohio river probably 3,000 feet. If the oil and gas could have risen from below, passing through this great depth of shales, they would have continued their ascent and been wasted at the surface long before man appeared. This specific example can be duplicated in some form in every great oil or gas field. Fortunately parts of the geological scale are impervious, for otherwise oil or gas in large quantities could not exist.

If the inorganic or chemical theory were true it would be reasonable to expect petroleum and natural gas in igneous rocks since they have been highly heated, and hence in a condition favorable for the production of these fuels. Experience, however, has shown that neither oil nor gas is found in rocks of this kind. So far as the writer knows there is no exception to this statement.

THE ORGANIC OR GEOLOGICAL THEORIES.

These theories have only one point in common; all assign organic matter as the origin of petroleum and natural gas. Some contend that these products have been derived wholly from animal matter, others entirely from vegetable matter, and others still from both. There is likewise no general agreement as to the method by which the change has been produced. Another point of difference still is the position which the products now have when compared to that which the organic matter once occupied. Some regard them as identical; that is, the petroleum and natural gas now occupy the same rocks that the organic matter from which the fuels in question were formed once occupied, while others contend that the organic matter originally occupied a lower position than the resultant products now do. A third view adopts each in part; that is one theory is correct when applied to some fields but not when applied to others.

If oil and gas have been produced from organic matter then these products or others closely related ought to be secured artificially. Much experimenting has been done along this line and with considerable success. Daubree has been a pioneer in this work, and by treating wood with superheated steam obtained a product having the odor of petroleum. Warren and Storer by the distillation of a soap made from Menhaden oil obtained members of the methane, ethylene and benzene groups similar to those found in petroleum. In 1888 a more elaborate report was made by Engler who also started with Menhaden oil. By distilling this he obtained a series of oils such as are obtained by refining petroleum, and among these was an illuminating oil "indistinguishable from commercial kerosene." He later tried to secure similar results from dried animal matter such as fish, but was unsuccessful. From this he concluded that petroleum has been formed from the fats only. The agency, he thinks, was heat and pressure or the latter alone. Sadtler in 1897 announced the results of his experiments on vegetable matter. By distilling linseed oil under pressure, he obtained an oil resembling petroleum and also a scale of paraffine. It is seen from these experiments that products very closely resembling petroleum have been secured artificially from both animal and vegetable matter.

But how have these products been produced in nature from organic matter? This from the nature of the problem is not susceptible of proof. However, there is perhaps greater uniformity of opinion than in the inorganic theories.

Peckham regards petroleum to have been produced by the distillation of animal and plant remains at low temperatures. The heat, he thinks, was a result of friction produced by the elevation of the Appalachian mountains and was sufficient to metamorphose the rocks; but this applies only to the oils of such states as Pennsylvania, New York, West Virginia

and eastern Ohio, and the product in this field he considered to have been obtained from vegetable matter. Other oils, especially those found in shales in California, he classed as animal in origin. The different grades of oil found in the Appalachian field were in his judgment the result of fractional distillation, and natural gas was an incidental product. The great reservoirs in these states he thought were produced in rocks lying much below those which now contain them.

Phillips assigns a vegetable origin to petroleum, claiming that the change has taken place under water, and hence in the absence of air. The first changes were relatively rapid, and the later one, which is directly responsible for the petroleum, much slower. Apparently this theory does not require great heat.

Newberry has published an elaborate theory to explain the origin of the oil and gas in the Appalachian field. He makes the source the plant remains in the great shales lying in the Lower Carboniferous and upper Devonian formations, the products rising to the horizon where now found. That these shales contain a large quantity of organic matter has long been known. By distilling the Huron shales of Ohio from 10 to 20 gallons of oil per ton can be secured. These shales have often a great thickness and cover a very large area, and hence must contain a vast quantity of hydrocarbon compounds.

Newberry does not appear to use the term distillation in the ordinary sense. This, as is well known, requires a high temperature. Thus Engel in the work on Menhaden oil already referred to, began with a temperature of 320 degrees C. under a pressure of 10 atmospheres, and later increased the heat to 400 degrees C., at the same time decreasing the pressure to 4 atmospheres. Newberry, however, thought that the changes took place at low temperatures.

Dr. Orton has written elaborately on the subject. He considered both petroleum and natural gas to have been derived from organic matter, animals in some cases, plants in others. This could be determined, he thought, by the nature of the product; thus the petroleum and natural gas of northwestern Ohio contain sulphur and nitrogen compounds, and so have been derived from animal matter. He held the same view of the small quantity of oil derived from the Cincinnati and Utica shales in Ohio and the shale oil of California.

The oil and gas in the great Appalachian field, on the other hand, he considered of vegetable origin, making as the source plants found in the great shales underlying the oil and gas bearing formation. In Ohio these would be principally the Ohio shales (Devonian) and the Cuyahoga shales (Sub-Carboniferous). The changes were made without high temperature.

Kraemer and Spilker in 1899 announced the results of experiments on an ooze found beneath a bed of peat lying north of Berlin. The ooze has

an average thickness of about 22 feet, and the solid part consists of diatoms, desmids and higher plants. On treating this with benzol and alcohol a residue was secured which closely resembled paraffine. By treating a small quantity of the ooze with dilute hydrochloric acid, a wax was obtained which very closely resembled ozokerite. From further tests the authors concluded that the two substances—paraffine and ozokerite—have had a common origin. Previous to these results Pfitzer had discovered drops of oil in the plasma of some diatoms. These observations are of great interest because of their bearing on the origin of petroleum.

The following interesting theory has been furnished by Dr. Charles B. Morrey, Professor of Bacteriology in the Ohio State University. As will be seen it differs radically from the well known theories of Peckham, Newberry, Phillips and Orton:

“In accounting for the origin of oil and gas from organic matter, geologists have been unable to furnish the agent which might have brought about the proper decomposition, since there is no evidence of the action of heat on the vegetable and animal remains in Ohio fields at least.

“Now the only other agent with which we are acquainted which can produce the same compounds as we have in destructive distillation of organic matter are *Bacteria*. These organisms acting in the absence of air—i. e., under water—produce from vegetable matter marsh gas, olefiant gas and other hydrocarbons as well, a process frequently shown by experiment and occurring in very sluggish streams, marshes or bogs at the present time. The compounds produced here partly escape into the air and are in part retained in the mud, as a simple stirring of this shows, and there is abundant reason for believing that this same process has been going on for ages past. B. Renault has found bacteria in fossil remains of various epochs—Jurassic, Permian, Carboniferous and Devonian.

“In the formation of shales by stream deposits, wave action, and ocean currents, quantities of organic matter, largely vegetable, were deposited in the mud giving rise to such shales, and along with this material, bacteria in enormous numbers. These bacteria acting in the absence of air would form marsh gas and heavier hydrocarbons just as takes place today. This decomposition could go on not only in shallow water but also at great depths, as experiments have shown that the action of bacteria is not prevented by a water pressure of 600 atmospheres corresponding to a depth of more than 15,000 feet of water. Bacterial decomposition would continue until all the organic matter was broken up into compounds no longer capable of being attacked—the hydrocarbons among others—or until the bacteria were killed by an accumulation of their own products. In the latter case we should probably find a much higher percentage of

carbon as in coal, than we have in oil or gas. Or the decomposition could also have been stopped by a drying out of the shales—the presence of a certain amount of water being necessary for bacterial growth. Where animal remains in larger quantities were decomposed, we would have not only the hydrocarbons, but also various nitrogen and sulphur compounds exactly as we find in limestone oils.

“So that I should say that petroleum of the Pennsylvania type and gas in similar situations were formed in the mud of which shales were composed, from the time the mud was first deposited and by the decomposing action of bacteria on the organic matter therein, and the formation continued until bacterial action was stopped in the ways above mentioned.

“In the case of limestone oils and gas, the bacterial decomposition would begin with the deposit of the first dead organism, so that these substances have arisen in such localities by the action of bacteria on the soft parts of those animals whose hard parts form the limestone.

“Whether there is still undecomposed organic matter in shales, limestone, etc., experiment alone can determine; probably not, however.

“Doubtless enormous quantities of gas and oil formed in the way above described escaped into the air and were lost, and what remained was retained in various mechanical ways which it is not my province to discuss.

“My reasons for believing that oil and gas have arisen in this way may be summarized as follows:

“1. Bacteria produce just these decompositions when acting in the absence of air.

“2. Bacteria were present in the formations along with other organic matter.

“3. Bacteria are the only agents known which can produce such decompositions except heat.

“4. The action of heat (in the Ohio fields at least) is excluded by geologic evidence.”

But were the fuels in question derived from organic matter which was once imbedded in the same rocks that now contain the oil and gas, or were the latter formed from organic matter which was deposited originally in rocks lying beneath those now containing these substances?

There are two different views on this matter, but the majority seems to favor the latter one. Dr. Orton regarded the oil and gas in the Trenton limestone to have been formed from animal matter which was entombed in that formation. In drilling wells in this the sand-pump sometimes brings up masses of shells showing that the rock in places is highly fossiliferous, and the same fact has long been known from the study of outcrops of the formation in southern Ohio and other states. With such

a supply of animal matter at hand, it seems altogether unnecessary to search for a source in some underlying formation.

However when the remaining oil and gas rocks are examined, the conclusions reached are not so positive. Thus the great gas wells in the central part of the state are obtained in a thin stratum of sand stone of Clinton age. Samples of this rock are not easily collected, and hence there is very little positive evidence bearing on the question as to its having contained organic matter. Lying below the gas sand are a few feet of dark colored shales concerning which we have little information. Examination of a few samples gave no evidence of an abundant fauna or flora. Below these in turn lie the Medina shales, having a thickness according to Orton ranging from 50 to 150 feet, and commonly a red color. They have been classed in the Ohio reports as generally non-fossiliferous. These could not have been the source of the great body of gas in the Clinton rock. The next formation met in descending the geological scale is the Cincinnati series consisting of shales and thin bedded limestones. These are very rich in animal remains, but the gas in question does not appear to have originated from such material, for the analysis already given shows the gas free from sulphur compounds. However, if there were not this objection we would still be confronted with a serious one—that of explaining how the gas could reach the Clinton when lying between it and the Cincinnati series are many feet of shales. It has long been the custom of geologists to have as a condition for the occurrence of a reservoir of gas, an impervious bed lying above the rock containing the fuel in question. This is usually shale, a rock which from its fine texture seems admirably suited for the purpose. Now if a bed of shale lying above an oil or gas rock will prevent the ascent of these substances, the same kind of rock lying below will also prevent oil or gas from rising and reaching the formation which now acts as a reservoir for these fuels. Shales appear impervious, and hence oil and gas cannot have passed through them. This, of course, excludes the theory that oil and gas have been produced from rocks lying beneath those which now contain the fuels. However, where a bed of shales lies immediately below a porous rock, oil or gas might pass from the top of these shales into the overlying formation, but they could not pass from lower points in the shales into the superimposed rock. This view seems necessary but it does not simplify the main question—that of the origin of natural gas in the Clinton sand. It must be remembered, however, that if the absence of organic remains in the Clinton could be demonstrated, it would not prove that such remains never existed in the rock. Thus many of our limestones contain in places very little evidence of animal origin, the hard parts having been ground to a mud before the rock was cemented. Now if this is true of such material, it would be more

conspicuously so of plant remains, for it is of these that the Clinton gas seems to have been formed.

The same difficulty is met in attempting to explain the origin of the oil and gas in the Lower Carboniferous and Coal Measures. Take as an illustration the Berea grit. Dr. Orton says: "It is poor in fossils, but not entirely destitute of them. Fish remains are the most conspicuous, but by far the rarest of the forms it contains. Plant impressions are also unusual through most of the formations, but in northern Ohio there is a certain part of the stratum in which they are quite abundant. They sometimes accumulate in quantity, enough to be known as coal blossoms, the carbonaceous streaks that separate the sandstone beds varying in thickness from a line to a half inch."¹ This formation nearly always gives at least a show of oil or gas, and in places contains reservoirs of great importance. Lying beneath the Berea grit are the Bedford shales, having a thickness ranging from 50 to 150 feet, and according to Orton sparsely fossiliferous. Beneath these in turn are the great Ohio shales having a thickness in the eastern part of the state exceeding 2,500 feet, and being rich in organic matter. It is these that Newberry, Orton and others have regarded as the source of the oil and gas in the Berea and perhaps in the higher sands such as the Big Injun. But again the old question arises—how could oil and gas pass through the shales as was necessary before these products could reach the Berea or higher sand?

The present condition of the Ohio shales themselves bears testimony against this theory. Along the shore of Lake Erie they outcrop, and the same is true in the central portion of the state, extending from near Sandusky to the Ohio river. This condition has existed for a long time, even as reckoned by geologists. If oil and gas can rise through these rocks, they would have reached the surface and been lost ages ago. As is well known, however, such has not been the case. Along the lake shore numerous wells have been drilled and small supplies of both oil and gas have been found. A well drilled in 1895 at North Kingsville, Ashtabula county, gave the following results:²

	Feet.
Soil	9
Gas found at	32
Well cased at.....	35
Gas supply for the boiler at	60

Increased flows of gas were obtained at 76, 143, 161, 187, 221, 223, 252, 298, 312, 317 and 320 feet. Several months after completion the flow of gas was measured and found to be over 37,000 cubic feet per day. A few miles farther south another well was drilled and with similar results. Gas was found at several horizons, ranging in

¹*Geol. Sur. of Ohio, Vol. VII., p. 29.*

²*Ibid., Vol. VI., p. 423.*

depth from 98 to 372 feet. Oil was found at 450 feet and at 632 feet. At Geneva gas was found at depths ranging from 130 to 1,375 feet, the strongest flow having been obtained at the latter depth. Similar results have been found at many other points. It is significant that in those parts of Ohio where the shales in question are covered by Carboniferous strata, the former do not appear to be any richer in oil or gas than where they are uncovered. This certainly would not be true unless the shales themselves are impervious.

The following extract from Dr. Orton's report expresses very clearly the quantities of organic matter which these shales now contain:¹

"Although no great accumulations of oil are found in the shales proper, it would be wrong to infer that they are poor in petroleum. On the contrary, they contain much more than any other strata with which they are associated, the great sandstone reservoirs not excepted, but it is in a distributed condition that the petroleum occurs. The entire body of the shale carries a determinable percentage. The percentage is small, but the aggregate is vastly larger to the square mile than any square mile of the most prolific oil field that has ever yielded to the drill. Prof. N. W. Lord, chemist of the Survey, determined the petroleum existing as such in normal samples of Ohio black shale. He found the amount to be slightly less than one-fifth of one per cent., but he learned from his investigations that the finer the divisions of the shale, the larger was the percentage of oil obtained. It was therefore certain that the true percentage exceeded that reported; further than this, there had undoubtedly been some loss of the petroleum from the exposure of the shale, but even on the percentage obtained, if the shale series is counted at the low average thickness of 1,000 feet for its entire area, the total amount per square mile passes far beyond the limits of clear comprehension.

"Calculations show that it would exceed ten million barrels (10,000,000) to the square mile, and such figures stand, of course, merely for numbers that turn up in arithmetical processes, but to which we are unable to attach any definite significance further than to recognize in them very large numbers.

"The oil-stock of the shales is large, as thus appears, but the oil production is very small. The case, however, stands somewhat better with natural gas. Here again the lack of sandstone reservoirs forbids large accumulations, but the shales themselves yield gas in such volume as to become of considerable economic importance. There can be no question but that the gas is derived directly from the oil of the shales. Deep as the drill goes down the shales are found charged to the extent noted above with petroleum, which begins to break up at once into volatile compounds when exposed to the air."

¹*Geol. Sur. of Ohio, Vol. VI., p. 413-4.*

That it is possible to have in rocks a large quantity of organic matter without direct evidence of its origin in the form of abundant fossil remains is well illustrated in these shales. Dr. Orton states:

"The shales are for the most part poor in fossils, except in those of microscopic size. Banks representing a score or more of feet in vertical column often fail to reward a careful search with a single specimen of vertebrate, molluscan or articulate life, and as far as the unaided eye is concerned, they are almost equally barren of vegetable remains. Occasionally, however, fossiliferous bands are found, the contents of which serve to determine the geological age and equivalence of the portion of the series in which they occur."¹

II. GEOLOGICAL CONDITIONS UNDER WHICH OIL AND GAS ARE FOUND.

There are three conditions which have been strongly advocated by geologists:

1. A porous rock to contain the oil or gas.
2. An impervious cover.
3. Geological structure of the rocks which will permit the accumulation of oil and gas from relatively large areas into smaller ones.

All agree as to the necessity of a reservoir-rock. The one essential of this is porosity. Very fine grained rocks cannot, therefore, serve this purpose, and for this reason shales are not important oil or gas containing rocks. In Ohio three types are found—limestones, sandstones and conglomerates. The limestones have been elaborately described by Orton. As has already been stated, they contain the immense repositories in the northwestern part of the state, but are not productive in other fields in Ohio. Analyses show the rocks to be strongly magnesian and Orton placed much weight on this feature, since limestones of this type are notably porous when compared with those of the ordinary or calcareous type.

Recent developments in Texas, however, show that calcareous limestones may serve as a reservoir for oil. Thus according to an analysis made by Worrell, the oil rock in the great Beaumont field contains over 97 per cent. carbonate of lime. When it is considered that this rock has yielded by far the greatest wells yet drilled in the United States, it is apparent that ordinary limestone may serve as efficiently as that of the magnesian type.

Sandstone is the most common reservoir rock, and perhaps the Berea grit is the best illustration of this. The rock is composed of moderate sized grains of silica. However, it appears compact, and the quantity of oil which it contains often seems out of proportion to the porosity of the rock. In fact it is hard to believe that this formation ever contained the

¹*Geol. Sur. of Ohio, Vol. VII., p. 24.*

great volume of oil that has been taken from it in places,, as for illustration the Scio field. This appears all the more remarkable when it is recalled that the so-called pay-streak usually composes a small part only of the rock. Sands of this character do not yield great wells, but their life as a rule is long. These characters are certainly in harmony with the porosity of the rocks. The Berea is the finest grained of the important oil or gas sands of the state.

Sandstones grade imperceptibly into conglomerates, and hence it is not easy to say when one leaves off and the other begins. Many of the so-called conglomerates of Ohio vary in texture rapidly, changing in a short distance to a sandstone. The Big Injun, Keener, Macksburg 500-foot, and First Cow Run sands are conglomeritic in places, but more commonly they are coarse sandstones. They make excellent reservoir rocks, and the wells sometimes have large initial productions. The decline, however, is almost invariably more rapid than in the Berea. The production is often long maintained, as is illustrated by wells at Joy, Cow Run and other places.

Shales are not important sources of either oil or gas though small quantities of both are often found in them. In the coarser grades of these rocks oil and gas may occupy the spaces between grains, but in the finer grades the fuels in question probably lie between the layers of the rock rather than between the component particles.

The necessity of an impervious cover is apparent. Without it the gas would have risen to the surface and been lost ages ago, and the more volatile parts at least of the oil would have met a similar fate. Not uncommonly the rock is very compact at the top forming the "cap" of the driller. This may serve to retain the oil and gas below. Generally, however, a bed of shales lies above the formation, and serves to prevent the ascent of the fluids. A thin bed of fine clay also would serve admirably to seal in the oil and gas.

The third geological condition is structural, and is commonly known as the anticline or terrace. This permits the oil and gas of a relatively large area to accumulate in a much smaller one. This theory has been strongly urged by White and Orton, and in a more general way by others at an earlier date. It is very generally accepted by geologists and almost equally so by laymen. In many cases important reservoirs have been located by applying the principle. Thus in eastern Ohio Orton predicted the presence of oil in the Moore's Junction field west of Marietta, and correctly located the Snyder and Bricker pools in Harrison county. White has been still more successful in West Virginia and Pennsylvania. Among other pools in eastern Ohio that have been demonstrated to lie on anticlinals may be mentioned Macksburg, Cow Run, Newell's Run and Sistersville. In the northwestern part of our state the rocks form a broad arch, dipping to the northwest on one side and to the southeast on the other.

This is readily seen by examining a geological map. The arch contains minor irregularities, such as the well known Findlay break described by Orton and mentioned in the discussion of Hancock and Wood counties in the earlier parts of this volume. It was on or near this break that many of the largest gas wells were found, and in general it may be stated that the richest oil territory has been found where the Trenton rock lies highest.

In the southwestern part of the Trenton field, in Mercer, Auglaize and Shelby counties the rock in question rises to the south and is exposed in the bed of the Ohio river at Cincinnati. This seems to exclude the idea of an arch in that part of the field. From Mercer county north the dip in the Trenton rock is small, the structure being more of a terrace than an anticline.

It cannot be said that all oil or gas fields in Ohio are associated with anticlines or terraces. Thus the great gas field at Sugar Grove, the oil fields at Chester Hill, Corning, Scio and several smaller reservoirs have not as yet been demonstrated to lie on these structures. However, the reverse has not been conclusively demonstrated, and the fields in question may still fall in with the anticline or terrace theory. The great reservoir at Beaumont, Texas, also appears to stand in opposition to this theory.

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CHAPTER I.

A BRIEF HISTORY OF CEMENT.

Cummings in his "American Cements" says: "The fact is, the history of natural rock cement reaches so far back into the early ages, that it is impossible to learn precisely the date of its earliest fabrication. But we do know that ancient Egyptians made natural cement 4,000 years ago, which set under water. The Romans over 2,000 years ago used it in sewer and water mains, fountains, etc. Prior to this an aqueduct over 70 miles in length was built for the ancient city of Carthage. At one place it was carried across a valley on arches over 100 feet high, 1,000 arches in the line. Immense quantities of natural cement were used in its construction. Some of these arches are still standing. At one point where the arches are the highest, a piece over 100 feet long has fallen from the top of the aqueduct to the rocks below and still lies there intact, unbroken, illustrating the toughness, tenacity and durability of the natural rock cement."

Shadwell in "The Architectural History of the City of Rome" says that the earliest use of lime mortar among the Romans dates back to 175 B. C. to the construction of the "Emporium," the walls of which are a mass of concrete, rough stone and mortar. From this time on much concrete was used in the walls of buildings, fortifications, aqueducts, etc.

The Colosseum, built by Vespasian and Titus, A. D. 75 to 80, was largely of concrete walls with cut Travertine stone, having the inner walls faced with brick.

The aqueducts, in order to make them impervious, were lined with a cement mortar composed of crushed fragments of brick with fresh lime, called by the early Romans, "Opus signinum;" it is still known and used in Rome under the name "cocciopesto."

Another form of concrete known as "Opus Reticulatum," looks like brick work, but is composed of a lime concrete wall having wedge shaped pieces of Tufa driven into the face of the wall before the concrete attained full set. It is said that some 25 or 30 years ago an attempt to destroy such a wall on the Quirinal, failed on account of the immense expense required due to the extreme hardness and toughness of the concrete, such walls being indestructible except by the use of dynamite.

This failure seems to imply one of two things, either that ancient concrete was very superior in toughness to anything we now construct, or else, that the Latin race lacks much of the vigor and persistency which the Yankees possess ; for, elsewhere in this paper an account is given of the successful removal of a solid concrete monolith of great toughness in preparing the foundations of the new post office building in Chicago.

The dome of the Pantheon, which was erected at the beginning of the Christian era, is of concrete supported in a frame work of brick arches. It has an internal diameter of 142 feet. For 2,000 years nature has been expending her energies upon the structure, but it still survives to tell the story of the durability of concrete. Figure 1 shows this remarkable building.

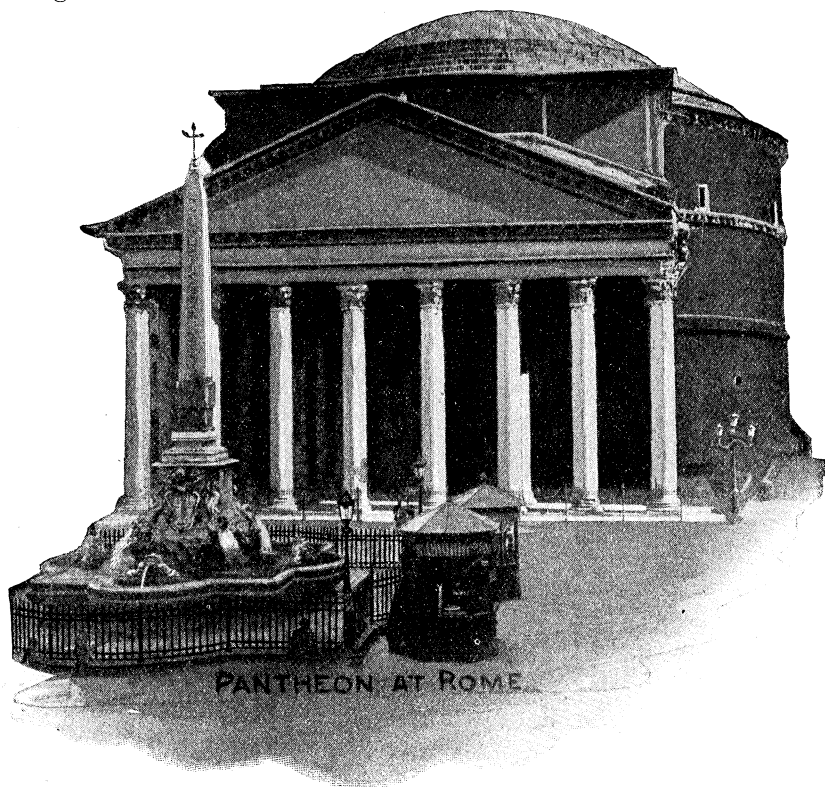


Fig. 1.—View of the Pantheon at Rome.

"The Pantheon at Rome is the most perfect existing classical building in that famous old city. It was built by Agrippa, 27 B. C., nearly 2,000 years ago. The circular walls are about 20 feet in thickness, and the roof is a hemispherical cement concrete dome with a thirty-foot opening in the top and spanning in the clear 142 feet 6 inches. This is the most remarkable instance in the world's history showing the great strength, durability and permanence in cement concrete construction. It has baffled the destructive elements of time for nineteen centuries and shows not a single crack to-day."

Cummings says that in Mexico and Peru, natural rock cement was used so long ago in stone masonry that the stone has worn away leaving the projecting mortar joints.

MODERN CEMENTS.

Cements, as we know them today—meaning either natural or Portland cements—were not known commercially until the beginning of the last century. Indeed, Portland cement has not been manufactured on a commercial scale much longer than 50 years. The Roman cement was a natural cement, even more natural than cement bearing that name today—because it needed no burning, but was manufactured directly from the volcanic ashes around Mount Vesuvius, especially those found near Pozzuoli, and it was therefore called Pozzuolana.

Cements in England.—The first cements manufactured in modern times were made in England and were called “Roman Cements” from their resemblance to the old Roman cements which hardened under water. In 1756 while preparing to build the Eddystone light-house, John Smeaton began investigations which led to the discovery that argillaceous limestones produced limes that would set under water, called hydraulic limes. He carried his investigation far enough to secure a good hydraulic lime or natural cement, which through its durability in the Eddystone light-house gave Smeaton lasting fame in engineering science. The Eddystone light-house built in 1756-58 by Smeaton was on a very exposed coast in the English Channel south of Plymouth. It was rebuilt in 1882, not because of the failure of Smeaton’s cement, but due to the wearing away of the solid rock beneath the tower.

In 1796, Joseph Parker, manufactured a Roman cement by calcining and crushing septaria nodules found on the Isle of Sheppey just off the coast of Kent, England. Parker’s patent, dated June 28, 1796, and numbered 2120, claims the invention of: “A certain Cement of Terras (trass) to be Used in Aquatic and other Buildings, and Stucco Work.”

He described his process as follows:

“The principle and nature of said invention consists in reducing to powder certain stones or argillaceous productions, called noddles of clay, and using that powder with water so as to form a water (mortar?) or cement stronger and harder than any mortar or cement now prepared by artificial means. I do not know of any precise general term for these Noddles (?) of clay; but I mean by them certain stones of clay or concretions of clay, containing veins of calcareous matter, having frequently but not always water in the center, the cavity of which is covered with small crystals of the above calcareous matter—being burned with heat stronger than that used for burning lime—and by having water thrown upon them, and being reduced to powder after burning, and being mixed with water just sufficient to make them into paste, become indurated in water in the space of an hour, or thereabouts. Any argillaceous stone, then, corresponding with this description, whether known by the name noddles of clay, or any other name, is the sort and kind only that I mean to appropriate to my own use in the fermentation (formation?) of my cement.”

Natural cement was produced at Boulogne, France, in 1802, from *Septaria*, called Boulogne pebbles.

Edgar Dobbs, of Southwark, London, took out a patent in 1810 on a manufactured artificial hydraulic lime, or cement, made by mixing carbonate of lime and clay, drying, molding and burning sufficiently to expel the carbonic acid without vitrifying the substances.

Joseph Aspdin, a brick mason of Leeds, England, first manufactured a real artificial cement, which process he patented in 1824 and called the product Portland cement because the artificial stone produced from such cement was very similar in character and appearance to the noted building stone obtained in the quarries on the island of Portland, in Dorsetshire, England.

Portland cement did not become an acceptable building material, however, until John Grant, an eminent engineer, employed on the London drainage works in 1850, had thoroughly tested it and discussed its use in a scientific manner, and had written several clever articles upon the subject for the institute of civil engineers. From that day until the present time it has been an important material in English construction. England led in the manufacture and use of Portland cement for 25 years, but Germany finally took the lead in its production and it is only within the last two years that the United States has passed all other countries and approached Germany in the development of the cement industry.

In 1900, England produced between 7 and 8 million barrels of Portland cement.

Cements in France.—The growth of the cement industry in France has not been so marked as it has been in several other countries, but her chemists have led in first establishing the true principles of hydraulic cements. In 1802 natural cement was produced at Boulogne from *Septaria*. In 1813 to 1818 M. Vicat produced hydraulic lime or natural cement artificially by mixing chalks and clays. In 1846 the manufacture of Portland cement was first begun in France near Boulogne.

The output of Portland cement in France for 1900 was about 3,500,000 barrels.

Cements in Germany.—In Germany the first Portland cement works were established at Stettin, in 1855, in the now famous Hamburg Portland cement district. The growth of the production of Portland cement in Germany was almost as phenomenal as it has been during late years in the United States. From a production of 30,000 barrels in 1855, the production grew until in 1877, 29 factories produced 2,400,000 barrels. In 1886, 42 factories produced 5,700,000 barrels. In 1900, 70 factories produced nearly 20,000,000 barrels.

For many years Germany has exported two to four million barrels of cement each year to the United States besides its exports to other countries.

In 1901, however, the exports of German cements to the United States fell below 600,000 barrels.

Cements in the United States.—The first discovery and manufacture of cement in the United States was made in 1818 by Canvass White, who took out a patent on Roman cement which he manufactured from the natural rock near Fayetteville, New York. This was used in the masonry work on the Erie canal.

A diary,¹ kept by one of the ancestors of Mr. Samuel T. Wagner, M. Am. Soc. C. E., during a trip over the Erie canal while it was under construction, reads as follows: "An important discovery by Mr. White of a lime whose properties resemble and are equal to the Roman cement aided the construction and greatly insures the permanent duration of the massive and important masonry of this great work. Experience and time have established its power to harden under water. It contains 35 parts carbonic acid, 25 parts lime, 15 parts silex, 16 parts alumine, 2 parts water and 1 part oxide of iron. It is calcined, ground and mixed with an equal weight of sand and but little water. It is found in inexhaustible quantities."

In 1824, natural cement rock was found at Williamsville, Erie county, New York. This discovery was also brought about by the necessities of the Erie canal. A natural rock cement was manufactured at Kensington, Conn., in 1826, while the first works in the famous Rosendale district in New York were not established until 1828.

Quoting from Mr. Robert W. Lesley's paper, "History of the Portland Cement Industry in the United States," he says:

"The first large public works built in this country were the canals, and the most necessary thing to build a canal was mortar that would hold the stones together at the locks, or walls, under water. Consequently, wherever canals were to be built, there was a search for cement rocks, and all the earliest works in this country were established on the lines of canals. Thus, on the Chesapeake and Ohio are the Cumberland and Round Top works; on the Lehigh canal the works at Siegfried and Coplay, Pa.; on the Richmond and Allegheny, the works at Balcony Falls, Va.; on the Delaware and Hudson canal, the large group of works at Rosendale and Kingston, and at the Falls of the Ohio canal, the large aggregation of works at Louisville."

He might have added also, on the Michigan and Illinois canal are the works at Utica, Ill. The works at Louisville were established about 1829, while the works at Utica, Ill., were founded in 1836-38.

The First Portland Cement in the United States.—The first Portland cement manufactured in this country was made from natural rock by Mr. David O. Saylor, of Coplay, Pa. He had been making natural rock cement for several years, when he turned his attention to the production of a more perfect cement in the early seventies. By careful selection, grind-

¹ *Eng. Record*, Oct. 3, 1903.

ing and mixing he produced a Portland cement which he exhibited at the Centennial Exhibition in 1876 at Philadelphia. This cement compared favorably with the imported cements of that date.

Up to 1880 five other works were established as follows: At Rondout, N. Y., Kalamazoo, Mich., Wampum, Pa., South Bend, Ind., and Rockland, Me. Of these six works but three have made sufficient success to survive. In reality the Portland cement industry in the United States as a commercial success dates back no further than 1882; 21 years of Portland cement life brings us to the year of its majority, 1903. Below is given a table showing the production of Portland cement in this country and the importation of foreign cements from 1880 to 1902 inclusive.

TABLE I.
Table Showing Production of American Portland Cement, and Im-
portation of Foreign Portland Cement for years
1880 to 1902, inclusive.

Year.	American.	Foreign.	Year.	American.	Foreign.
	Barrels.	Barrels.		Barrels.	Barrels.
1880	42,000		1891	454,813	2,988,313
1881	60,000		1892	547,440	2,440,654
1882	85,000	370,406	1893	590,652	2,674,149
1883	90,000	456,418	1894	798,757	2,638,107
1884	100,000	585,768	1895	990,324	2,997,395
1885	150,000	554,396	1896	1,543,023	2,989,597
1886	150,000	915,255	1897	2,677,775	2,090,924
1887	250,000	1,514,095	1898	3,692,284	2,013,818
1888	250,000	1,835,504	1899	5,652,266	2,108,388
1889	300,000	1,740,536	1900	8,482,020	2,386,683
1890	335,500	1,940,186	1901	12,711,225	939,330
			1902	17,230,644	1,961,413

CHAPTER II

THE USES OF CEMENT IN MORTARS.

There are three general forms in which cement is used, namely: (1) in mortars, (2) in plain concrete and (3) in reinforced or steel concrete construction.

As a mortar, it may be used either in a neat paste, or as a real mortar of cement mixed with sand. In the mortar form it is used for jointing all classes of masonry, for plastering walls and masonry surfaces, for fillers in street paving, for nearly all classes of ornamental work, for roofing-tile, for special processes of hardening quicksand in order to permit of excavation, for a protective coating to the metal work of bridges and viaducts to prevent rust and corrosion from the smoke blast of locomotives, etc., etc.

THE DEVELOPMENT.

Cement was undoubtedly first used in the form of mortar in laying stone or brick masonry. If a history of the development of masonry were written, the chronological steps of its progress would probably assume the following order: first, rough stones piled loosely in wall or pier form; second, selected stones with flat or squared surfaces set up in more regular forms, as was done by the ancient Hebrews in building their altars; third, selected stones, chipped into still more rectangular shapes and more carefully laid into regular forms of construction; fourth, to insure greater stability, mud paste, clay, or bitumen was used to cement the stones in place, and, finally, a mortar of lime or puzzuolana was discovered and used which insured permanency and durability to the work.

The oldest mortar so far discovered appears to be that found by Mr. Wm. Clarke, a civil engineer of England, who brought back for analysis a piece of mortar secured from the ruins of an ancient Phœnician temple near Larnaca on the island of Cypress. Mr. Wm. Wallace, in a paper read before the Mechanics' Institute, at Glasgow, says (speaking of this mortar which he had chemically analyzed): "Mr. Clarke supposes this to be the most ancient mortar in existence." He says further, "It is exceedingly hard and firm—and appears to have been made of a mixture of burnt lime, sharp sand and gravel." Of another specimen from the great Pyramid of Cheops, Mr. Wallace says, "Two specimens of mortar from the Pyramid of Cheops were examined, one from the interior and the other

from the outside—both present the same appearance, that of a mixture of plaster of a slightly pinkish color with crystallized selenite or gypsum. They do not appear to contain any sand. The mortar is easily reduced to fragments, but possesses a moderate degree of tenacity.” While the chemical analyses given by Mr. Wallace of both mortars do not parallel the usual Portland cement analyses, they do show that the ancient people knew how to manufacture the materials for a very durable mortar. Another specimen, Mr. Wallace says, “was taken from the Pnyx, in Athens, the platform from which Demosthenes and Pericles delivered many of their orations. It has been long exposed to the action of the weather, is very hard, and of grayish white color.”

While these specimens show the antiquity of mortar and how durable even a poor mortar may be, it is only within the last century and particularly the last decade that the high development of cement manufacture has brought into use mortars that are nearly perfect and almost indestructible.

THE ADVANTAGES OF CEMENT MORTAR OVER LIME MORTAR.

The uniform bearing and equality of support in the bed of each block of stone aids in securing strong and durable masonry. Lime mortar has furnished a masonry construction which has endured for centuries under trying conditions, yet for modern requirements in large warehouses, skyscraping office buildings and massive chimneys and bridge piers, a mortar which will more nearly equal in strength that of the building material used, is needed. Lime mortar simply furnishes a bed for the stone or brick, a bed which has but a fractional part of the crushing strength which stone or well made brick possess. With good cement mortar, however, a bed or joint is provided which continues to harden until frequently it will sustain greater strains without rupture than the body of the masonry itself can withstand.

With lime mortar there are several weak characteristics, namely, lack of tensile or cohesive strength, lack of crushing strength, porosity, inability to harden under water, and the necessity for contact with air, that the mortar may receive sufficient carbonic acid to thoroughly set.

Baker in his “Masonry Construction” gives the tensile strength of lime mortar of the proportions of 1 lime paste to 3 sand, at one year old, as 50 pounds per square inch. The present American Portland cements in mortars of the same proportions and age will run from 350 to 450 pounds per square inch.

The crushing strength of mortars are about 8 to 10 times their tensile strength and the same relative difference still exists between lime and Portland cement mortars, making the compression strength of Portland cement mortar from 3,500 to 4,500 pounds per square inch.

The average tensile strength of 12 American Portland cements in mortars of 1 cement and 3 sand, one month old, tested at one laboratory,

was 308 pounds per square inch. The average of six cements, at another laboratory, tested at six months of age, was 404 pounds. The average of 14 American and German cements at one year old, in proportions of 1 cement and 3 sand, was 361 pounds. The average of tests from ten different cement testers upon Giant Portland cement mortar, 1 cement and 3 sand, one year old, was 414 pounds; while 8 of the same testers gave results for 1 cement and 2 sand which averaged at one year old 492 pounds.

Actual crushing tests upon 12 inch cubes of Giant cement concrete, 3 months old, made in the proportions of 1 cement, 3 sand, and 5 broken stone, and tested at the government testing laboratory, gave crushing strengths varying from 3,081 pounds to 4,451 pounds per square inch and averaging over 4,000 pounds per square inch. Such concrete would support a column of its own material 3,600 feet high without crushing.

Where thick or heavy masonry work is to be built, the interior mortar joints are more or less excluded from contact with air, and consequently from the carbonic acid contained in the air, hence it is safe to conclude that it will take long periods of time for the lime mortar to become perfectly hardened. During this time the structure is liable to settlement and deformation, therefore the necessity of some more permanent and quickly hardening material for mortar.

Baker says in a note on lime mortar, "Lime mortar taken from the walls of ancient buildings has been found to be only 50 to 80 per cent. saturated with carbonic acid after nearly 2,000 years of exposure." "Lime mortar 2,000 years old has been found in subterranean vaults, in exactly the condition, except for a thin crust on top, of freshly mixed mortar."

For the heavy structures of the present day it is quite apparent that such defects would be dangerous.

The question of protection from the destructive action of the elements is often as important a factor of consideration with smaller structures as it is with the larger ones. The porosity of lime and mortar would allow moisture and temperature changes to affect the durability of such work. Cement mortar, upon the other hand, can be made impervious to water. It will set under water and without contact with air and will continue to gain strength for an unknown period of time. Cement mortar in the center of a thick wall will be practically as hard and durable as the exterior surface at the same age.

Lime mortar is of no value in submarine work. Good, durable masonry can not be laid in water without cement mortar. The fine breakwaters lately constructed by the United States Government at Buffalo and Cleveland, the concrete jetties at the mouth of the Mississippi river, the sea-walls around Galveston, Texas, and Havana, Cuba, all illustrate the value of cement in marine or hydraulic service.

NATURAL VERSUS PORTLAND CEMENT.

The question of whether to use natural or Portland cement mortar depends upon the strength required, upon the time which can be allowed for the mortar to gain sufficient strength for the immediate requirements of the work and upon the relative price of the two cements.

It may be that a rapid setting mortar is needed without great ultimate strength; if so, a natural cement will fulfill the requirements at a less cost than Portland cements. The time of setting of both natural and Portland cements varies so widely with different brands that only general limits may be stated. Natural cement usually begins to set in from five to forty minutes, and attains its permanent set in from twenty minutes to two and one-half hours, while Portland cement begins to set in from three-fourths of an hour to three hours and attains its final set in from two and one-half to eight hours. Some experimental Portlands, however, have been known to begin setting within three minutes and to have attained hard set in fifteen minutes.

To illustrate the question of relative cost and strength of the two cements, suppose the specifications for a certain structure call for a cement which shall develop an ultimate tensile strength in the work, of 200 pounds per square inch. Most of the natural cements in mortars of 1 cement to 2 sand will develop that strength in three months, and greater strength in six months or a year; while Portland cements will give similar strengths if mixed in the proportion of 1 cement to 4 or 5 sand. Assuming sand at \$1.25 per cubic yard, natural cement at 90 cents per barrel of 265 pounds, and Portland cement at \$2.50 per barrel of 380 pounds, the material for a cubic yard of mortar will cost:

TABLE 2.

For Portland Cement Proportions 1 to 5.		For Natural Cement Proportions 1 to 2.	
0.92 cu. yds. of sand at \$1.25	\$1.15	0.81 cu. yds. sand at \$1.25	\$1.01
1.12 bbls. cement at 2.50	2.80	2.49 bbls cement at .90	2.24
	<u>\$3.95</u>		<u>\$3.25</u>

From this comparison it is seen that a natural cement mortar of 1 cement, 2 sand, is 70 cents cheaper per cubic yard than a Portland cement mortar of 1 cement to 5 sand, both mixtures having about the same tensile strength. These comparisons, however, can only be made under known conditions, the proportions being dependent upon the weight of the cement and sand per cubic foot, the voids in the sand and the amount of water used in the mixing, while the amount saved is greatly influenced by the relative cost of the two cements and the cost of the sand.

When great ultimate strength is required, or when variable strains occur in a structure, Portland cement should be used.

MIXING THE MORTAR.

In preparing mortar the sand and cement should be thoroughly mixed dry and then water added and the mass carefully mixed again, until the mortar has a proper and uniform consistency to work easily and smoothly under the trowel. The strongest mortar for any given sand and cement is produced when sufficient cement is used to just fill all the voids in the sand with a thin coating of cement over each grain of sand. Sands vary greatly in their coefficient of uniformity. Some sands are all fine, some all coarse, while many are graded from very fine to very coarse. It follows, therefore, that a graded sand requires less cement to make a mortar having a given strength, than a sand which has uniform size. The voids in the latter sand amount to nearly 50 per cent. of the mass.

EFFECT OF VARIOUS SANDS UPON THE STRENGTH OF MORTAR.

Standard quartz sand has about 48 per cent. of voids in it when measured dry. Lake sand from Sandusky, Ohio, has about 35 to 37 per cent. of voids. Bank sand from Mock's sand bank northeast of Columbus, containing considerable clay or loam, has about 33 to 34 per cent. of voids.

A class in civil engineering at the Ohio State University carried on extensive tests during the winter term of 1902-03, with several brands of cement and the three kinds of sand named above. The characteristics of the sands were as follows:

TABLE 3.—Characteristics of Sands.

Kind of Sand.	Fineness—per cent. of sand remaining on a			Passing a No. 50 Sieve.	Voids Per Cent.	Weight per cu. ft.	Remarks.
	No. 20 Sieve.	No. 30 Sieve.	No. 50 Sieve.				
Crushed Quartz	0	100.0	0	0	47.5 to 49.0	83	Clean.
Lake Sand.	7.7	16.7	26.5	49.1	35 to 37	103	Clean.
Bank Sand.	11.6	37.0	33.4	18.0	33 to 34	102	Contains about 7% of loam.

Among the cements tested were the Atlas, Giant and Dyckerhoff brands of Portland cement. Seven and twenty-eight day tests were made. The results of the 28 day tests are given in table number 4. While the table shows quite a variation in the results obtained by the different testers, it certainly shows a remarkable uniformity in results when the

inexperience of the class is taken into consideration. One thing is quite markedly shown in this table and is corroborated by a large number of other tests, *i. e.*, the increase in tensile strength shown in the mortars made with the bank sand over those made with the other sands, especially in 1 to 2 or 1 to 3 mortars. One of the important features of the table is its comparative value for illustrating the personal factor in cement testing.

TABLE 4.
Twenty-eight Day Tests of Cement Mortar Briquettes—1903.

Tester.	Neat	Standard Sand.			Lake Sand.			Bank Sand.			Cement
		1-1	1-2	1-3	1-1	1-2	1-3	1-1	1-2	1-3	
C. L. Bushey.....	799	747	466	235	531	363	216	534	427	291	Atlas
L. Eysenbach.....	800	767	400	231	585	322	182	602	418	367	"
Edw. Thomas.....	770	524	359	210	474	221	222	*393	*302	*265	"
C. A. Melick.....	769	586	450	229	524	297	248	627	509	318	"
E. R. Brashear.....	778	701	240	246	595	380	204	656	556	390	"
W. J. Barry.....	813	700	442	206	560	312	203	632	492	342	"
Averages....	788	671	360	226	543	316	212	574	451	329	
C. W. Schubert...	908	783	505	252	630	458	278	640	550	354	Giant.
J. L. Murphy.....	970	633	456	245	600	436	226	571	431	318	"
C. L. Hill.....	1015	702	557	347	627	458	314	556	453	364	"
J. H. Chubb.....	1231	868	600	381	733	476	366	687	649	472	"
Averages....	1031	746	529	306	647	457	296	613	521	377	
J. H. Chubb.....	681	490	439	300	514	406	316	570	504	418	Dyck
J. L. Murphy.....	567	510	415	280	352	340	283	430	415	356	"
C. L. Hill.....	480	460	434	302	426	362	283	520	444	342	"
C. W. Schubert...	620	485	345	235	409	283	242	550	483	420	"
W. J. Barry.....	531	412	312	174	387	337	242	567	442	332	"
C. A. Melick.....	442	463	374	250	329	264	233	606	510	321	"
E. R. Brashear...	618	467	390	235	393	355	282	580	496	266	"
Edw. Thomas.....	487	360	308	234	312	215	212	390	212	232	"
L. Eysenbach.....	532	385	378	180	396	317	206	414	433	353	"
C. L. Bushey.....	640	425	370	189	354	300	249	418	425	345	"
Averages....	560	446	377	238	387	318	255	505	436	339	

* Composed of a mixed sand.

There may be several reasons for this increased strength of the bank sand mortar over the clean lake and quartz sands; but it is the writer's opinion that the principal reason is found in the smaller percentage of voids and the consequent surplus amount of cement which can go towards coating every particle in the aggregate. An examination of the table of characteristics of these sands shows that nearly one-half of the lake sand passes through a sieve of 2,500 meshes to the square inch. This accounts at once for the greater percentage of voids which must be thoroughly filled with cement in order to give greater strength to the mortar. This fine portion of the lake sand is composed of small, rounded and very smooth particles of quartz which naturally have no interlocking qualities, and must therefore depend entirely upon the adhesive powers of the ce-

ment upon their hard smooth surfaces to give strength to the mortar. The increased strength of the standard quartz mortar is largely due to the irregular rough grain of the sand which allows the grains to interlock and which also gives rough adhesion surfaces for the mortar contact.

THE EFFECT OF FINE SAND UPON THE STRENGTH OF MORTAR.

During the last winter the writer carried on a few tests to determine the effect of fine sand upon cement mortar. Similar and more extensive tests have been carried on by others, and in the main all agree that fine sand weakens cement mortar. The tests made by the writer are here presented in tabular form:

TABLE 5.
Effect of Fine Sand Upon Cement Mortar.

Lake Sand.	Per cent. of Water.	1 to 1 Mortar.			Per cent. of Water.	1 to 2 Mortar.	
		7 Days.	28 Days.	3 Mos.		7 Days.	28 Days.
Passing a No. 50 Sieve	11 15½ 18	315 426 394	395 578 533	668 617	14	315	367
Remaining on No. 50 Sieve	12½	517	514	629			
Remaining on No. 30 Sieve	12½	546	625	650			
Remaining on No. 20 Sieve	12½	495	599	613			
Remaining on No. 16 Sieve	12½	460	521	557			
Standard Quartz	12½	535	632	740			
Lake Sand Unsieved	14	500	581		12½	367	428

The number of the sieve designates the number of meshes to the linear inch. The tests show a marked increase in strength in mortars from fine to coarse sand, up to the size of the standard sand grain; from that size up the strength seems to decrease. It may be noted that the lake sand between the 20-30 sieves gives results comparable with the standard quartz mortars. The general results of these tests agree quite well with the results of other testers.

This series of tests was limited, only about 150 briquettes being broken. But the tests were made with great care in all details and will give a general idea of the action of fine sand upon cement mortar.

The unsieved lake sand occupies a place intermediate between the 50 and the 30 sieve. The results with different proportions of sand would probably differ slightly, but the two sets of briquettes broken from the 1 to 2 mortar indicate relatively similar results.

The following table taken from the "Directory of American Cement Industries," being the result of a series of tests made at the Holyoke Dam, Massachusetts, and supplemented by some of the writer's tests, shows the effect of adding sand to cement in reducing the strength of the mortar. All tests were tensile tests upon mortar briquettes 28 days old, made from high grade American Portland cements.

The results of the Holyoke test are given in column number 3 and the writer's tests in column number 4.

TABLE 6.
Strength of Various Grades of Mortar.

Cement.	Sand.	Tensile Strength. Pounds per square inch.	
		3	4
neat	0	889	873
1	1	805	581
1	2	589	428
1	3	343	275
1	4	204	211
1	5	133	161
1	6	121	
1	7	71	
1	8	53	
1	9	44	

EFFECT OF WATER UPON THE STRENGTH OF MORTAR.

Another feature plainly noticeable in mortars is the effect of the proportion of water used upon the strength of the mortar. Too much or too little water greatly reduces the strength of the mortar. Each sand and each cement influences the amount of water necessary to make the strongest mortars. In general, fine sands and loamy sands require more water than coarser and cleaner sands. Natural cements require more water than Portland cements. Mortars of 1 sand to 1 cement require more water than mortars having greater proportions of sand. Too little water making a stiff mortar, will increase the cost of working with it during construction and will decrease the perfect crystallization, thus decreasing the strength. Too much water acts as a dilutant, leaving the mortar porous when hardened and consequently not so strong as dense mortar. When mortar is placed where it will get very little additional moisture over that used in mixing it, sufficient water should be used to thoroughly hydrate the cement.

The writer in making laboratory tests found that a set of briquettes made from standard sand and Portland cement with 12½ per cent. of water, lost one-sixth of the water in the 24 hours that the briquettes remained in the air, although they were covered with a dampened cloth.

They regained one-half of the lost water after five days under water. If so much water is lost under such conditions, it is readily seen what a serious loss must occur in actual practice unless unusual care is taken to protect the mortar surface. There is no question but that this loss of water seriously impairs the strength of the mortar.

The three sets of tests with fine sand in table number 5 illustrate the effect obtained by using varying percentages of water. The table shows that from 7 to 10 per cent. of tensile strength is lost by using too much water, and from 30 to 40 per cent. by using too little. This illustrates the necessity of properly proportioning the water to the cement and sand used. The water used was proportioned by weight to the combined weight of sand and cement.

PERMEABILITY OF CEMENT MORTAR.

Work of Melick and Shepherd.—In 1899 and 1900, * Messrs. N. A. Melick and C. W. Shepherd, students in the Ohio State University, carried on, under the direction of the late Prof. C. N. Brown, a series of tests to determine the permeability of cement mortar. The question they sought to answer in reference to permeability, propounded by Mr. Julian Griggs, M. Am. Soc. C. E., Chief Engineer of the City of Columbus, Ohio, was this: "Is it necessary to use soap and alum and Silica Portland cement, or can a cheaper mixture be made impermeable."

The experiments were carried on with three kinds of sand; standard sand or crushed quartz passing a No. 20 sieve and being held upon a No. 30 sieve, lake sand, and a mixture of equal parts of lake sand and quartz. Medusa, Dyckerhoff and Silica Portland cement were used. The water pressure was applied to the cement mortar by means of a $\frac{3}{4}$ inch pipe threaded into the back of a metal disc, 15 inches in diameter. Bolted to the face of this disc was a flanged metal collar, 10 inches in diameter. Within the collar was rammed from 2 to 3 inches of the mortar, the permeability of which was to be tested. A neat cement filler $\frac{1}{8}$ inch to $\frac{1}{4}$ inch thick was troweled around the ring to prevent water leaking between the collar and the concrete. Figure 2 shows a section of collar filled with mortar ready to bolt on to the disc. The mortar was mixed so dry that water would just flush to the surface upon thorough ramming. Great care was taken to get uniform ramming over each portion of the disc; the rammer being constructed in the form of a double sector just fitting within the metal collar:

After investigation of actual work being done in Columbus, O., the young men estimated that in ramming, 8 foot-pounds of work were done upon each square inch of surface of the concrete which the city was laying. Hence they designed the rammer so that they could easily do a similar amount of work upon the ramming of the mortar into these collars.

*Taken from the thesis of Messrs. N. A. Melick and C. W. Shepherd, civil engineering graduates from the Ohio State University in 1900. The work was done at the suggestion and expense of the Engineers' Club, of Columbus, Ohio.

The mortar collars were kept in moist air for twenty-four hours and then stored in water for twenty-seven days before being tested. The water pressure in testing varied from 25 to 65 pounds per square inch.

It was found that discs which did not leak in twenty-four hours would never leak. To be considered permeable, it was decided that drops of water must collect upon the outer surface of the mortar disc. Where discs became damp, but sufficient moisture did not come through to collect into drops, they were considered to be porous, but not permeable.

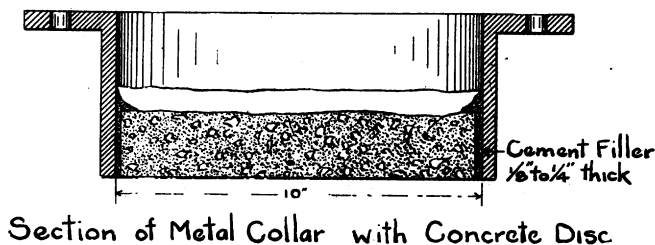


Figure 2.

The conclusions which they reached were:

First—In plain mortars, permeability depends upon the voids in the sand. A mortar not poorer than 1 cement to 2 sand will not leak, no matter what kind of sand is used. Mortars of 1 cement to 4 sand will be impermeable if made of a normal mixture of sand, that is, a sand having the normal variation in size of grains. Any mortar will become impermeable if the water acting against its face contains suspended matter.

Second.—Cement Coatings.—One quarter inch coating of neat cement will make mortar impermeable.

Third.—Soap and Alum.—Applications of soap and alum on very permeable mortars do not justify the expense. It is better to procure sand with less voids, or use a richer mortar. Soap and alum used in the mortar do not make it impermeable, at least from the beginning.

Work of Kettler and Sherman.—In 1901, Mr. F. C. Kettler and J. K. Sherman, students of the Ohio State University, continued the investigations upon the permeability of cement mortars, using varying percentages of water in mixing the mortars, and using loam in the sand. They also used grout washes on the surface to prevent permeability. The thickness of the mortar tested was $1\frac{1}{2}$ inches. Their method of ramming and testing was the same as in the previous tests. Their experiments with loam did not show any definite results effected. Loam with standard sand was very permeable, less so with lake sand.

In the use of a varying quantity of water used in mixing the mortar, it was found that mortar of standard sand was quite permeable, the permeability decreasing as the percentage of water in the mortar increased from 8 to 14 per cent. The permeability of the lake sand mortar was

much less than with the quartz, but showed no regularity with variations in the use of water in the mortar. The lowest permeability with lake sand mortar was obtained when 14 to 16 per cent. of water was used in the mortar. The wetter mortar required less tamping and more mortar to fill the collar, thus indicating a denser mixture.

In testing grout washings, the clear mortar disc was first tested under pressure, then washed with a grout of one part cement and one part water, allowed to set 24 hours and placed under pressure. Another washing was applied, the disc allowed to set 24 hours and tested again. According to the tests the first wash was most beneficial.

The final conclusions were:

The permeability of mortar depends upon—

- 1st. The ratio of sand to cement.
- 2nd. The voids in the sand.
- 3rd. The percentage of water used in making the mortar.
- 4th. The thickness of mortar.
- 5th. The head of water pressure.
- 6th. The amount of tamping.

The permeability can not be materially reduced by the application of soap and alum solutions, or by finely powdered loam used in the sand.

Permeability can be reduced—

- 1st. By the application of 1 to 5 coats of cement grout, the reduction amounting to from 70 to 98 per cent. of the initial leakage.
- 2nd. By a coating of neat cement mortar $\frac{1}{4}$ inch thick.
- 3rd. By the mortar surface standing under a head of water containing suspended matter.

LOAMY SAND.

The majority of engineers specify that the sand shall be clean and sharp. A series of tests carried on at the Ohio State University under the direction of Prof. C. E. Sherman, also the results obtained by a class in cement testing under the writer, seems to prove that clay or loam up to 15 per cent. of the weight of the sand adds strength to the mortar. If additional tests under the varied conditions arising in practice continue to prove satisfactory, this will mean a great economy in many pieces of work where bank sand can be substituted for lake or washed sand.

The series of tests referred to were carried on during the winters of 1901, 1902 and 1903, by eight students of the Ohio State University, grouped two and two in investigations upon the effect of clay and loam in sand upon cement mortar. Each thesis embraced the results of such tests with Dyckerhoff cement and some standard American Portland. The mortar was made of 1 part cement and 3 parts sand, a definite percentage of

the sand being clay or loam. Each thesis included three series of tests, one with standard quartz sand, one with lake sand, and one with equal proportions of the two mixed. In each series, separate tests were made with clay and with loam, used in the following proportions by weight of the sand, namely, 2, 4, 6, 8, 10, 12 and 15 per cent. A total of about ten thousand briquettes were broken. The same conclusions were reached in each of the four theses written, namely, that either clay or loam added to sand up to the limit of 15 per cent. by weight, did not have any injurious effect upon Portland cement mortar after the first two weeks and up to the limit of time which the tests covered, namely, 12 weeks.

On the contrary the clay and loam added considerably to the strength of the mortar. The results differed with different cements, and with the different sands. Their conclusions were that the chemical composition of the cement influenced the results to some degree. In some cases 10 per cent. seemed to give maximum results, but the majority of the tests showed that 15 per cent. of clay or loam gave the greatest strength. Clay uniformly gave higher results than loam. One detrimental result was definitely established, that mortars made from sand carrying clay or loam could not be placed under water safely, in less than 48 hours after mixing, because the loam softened and warped under the influence of water.

Thus, for subaqueous masonry it would be unsafe to use sand containing clay or loam in mortar. There is one plausible explanation for the increased strength obtained and that is in the addition of smaller particles of material which aid in filling up the voids in the sand. If 10 or 15 per cent. of fine sand was added to the ordinary standard quartz it would undoubtedly give stronger results than with the clear crushed quartz.

Before finally accepting these tests as conclusive, it would seem best to submit a series of briquettes to a long time test of at least two years, allowing them to weather and freeze under conditions similar to those to which actual structures would be submitted.

Work of Chubb and Chaffin.—Since writing the foregoing paragraphs upon the effects of loam and clay upon cement mortars, Messrs. J. H. Chubb and W. W. Chaffin, civil engineering students in the class of 1904, of the Ohio State University, have carried on another extensive set of tests under the writer's direction, upon loam in cement mortars, noting particularly the effect of weathering and temperature upon such mortars. They also carried the percentages of loam used up to 27 per cent. of the weight of the sand. The percentages of loam used were 10, 15, 18, 21, 24 and 27 per cent. by weight of the sand used in the mortar.

The cements used were Giant and Atlas. The sands used were standard, lake and bank sand. The loam used was the ordinary clay field loam from the university campus, dried and sifted through a number 40 sieve. The mortars were all made of 1 part of cement to 3 parts of sand by weight, the loam being a percentage of the 3 parts of sand. In

mixing the mortar, the water varied according to the loam used, but the mortar was kept as nearly as possible at the same consistency.

To obtain the effect of weathering, 10 briquettes were made at one time and alternate briquettes were selected and subjected to the outdoor conditions. All the briquettes were kept in moist air for 48 hours and then the outdoor set of 5 briquettes was put in an exposed place with about one or two inches of loose earth thrown over them, while the indoor set was placed in pans of water. They were allowed thus to remain until broken, the outside set being exposed to all kinds of weather. The tests were carried on over a period of 8 months.

The following conclusions were reached:

1. The curves from the plotted results plainly show that conclusions drawn from tests three months of age would not always safely hold for longer period tests.

2. The mortars containing the highest percentages of loam weathered better than the clean sand mortar and the mortars containing the lower percentages of loam. The curves, for similar mortars which were kept outside and inside, did not harmonize at all for the lower percentages of loam used, but for the higher percentages of loam, the curves paralleled each other, the outside stored mortars being slightly lower in strength up to the 8 month period, but gradually approaching each other as their age increased.

The deduction was, that the higher density of the mortars with larger percentages of loam prevented the rapid absorption of water and the consequent damage to the briquettes by freezing and thawing.

3. A cement mortar containing large percentages of loam will not reach its ultimate strength as quickly as one containing little or no loam.

The rate of increase in strength, however, becomes greater for large percentages of loam, over low percentages, as the age increases, at least up to the 8 months limit.

If a mortar is to be used in a structure which is to be immediately subjected to great stress, a sand should be used which does not contain more than 10 per cent. of loam. As ordinary bank sand does not contain more than 7 or 8 per cent. of loam it is quite safe to use bank sand for such buildings.

4. If the mortar is to be used under water, clean sand should be used.

5. Mortars exposed to the weather gain strength slower than those placed under water, but ultimately they attain equal strength.

The deduction was made, that mortar placed outside was frozen part of the time and was dependent upon the thawing and rains for the necessary amount of additional water for hardening which the briquettes on the inside could get at once.

6. The variations in the size of the grains of sand, or the percentage of voids, determines the amount of loam which can be added.

Comparing the sands used, the conclusion was, that the difference in strength shown by the several mixtures was due, largely, to the resulting density of the mortars.

7. The writer came to the conclusion after carefully weighing the evidence of the diagrams, that a mortar with 24 per cent. of loam in the sand is about the highest safe limit for Giant cement, while about 21 to 24 per cent. is the limit for Atlas cement.

The temperature diagram shows that the minimum temperature during the day was below freezing during most of the time of the first four months of the tests, while the maximum temperature was below freezing 58 days out of 90.

The precipitation was slightly above normal.

COLORED MORTARS.

Colored mortars are used for various purposes. Mortar for pointing is colored to match the brick or stone masonry or else in contrast to set the joint in relief. Concrete building stones are colored red, terra cotta, brown, or slate to resemble different natural building stones. Cement sidewalk surfaces are colored slate, black or brown to prevent the glare of light which the uncolored cement surfaces reflect. Physicians have claimed that the great prevalence of ophthalmia and other forms of weak eyes is frequently due to the blinding glare from cement paved walks and limestone paved roads. At any rate, it is well known that uncolored pavements are very taxing on the eyes during bright, clear weather.

Mosaic and tile work are now manufactured from cement by using certain coloring materials. The cement sets very hard and permits a high polish. No coloring containing acids or anything that will act upon the alkalies in the cement can be used. Vegetable or oil colors destroy or impair the strength of the cement. Dry mineral colors affect cement the least, although, with the exception of ultramarine, which contains much silica, all coloring materials reduce the strength and durability of cement mortar to a greater or less degree. Ultramarine in small quantities seems to strengthen the mortar slightly.

The iron oxides and ochres are used for all shades ranging from yellow to red and brown; Manganese dioxide and lamp-black for grays, slates and blacks; and ultramarines for the greens and blues. Manganese dioxide is better for slates and blacks than lamp-black, as the oil in the latter affects the strength of the mortar.

Several tables giving the materials to use for different colors with the proportions to be used are condensed and given below. Column number one is taken from a leaflet on Portland cement by the Buckeye Portland Cement Company; number two is taken from C. C. Brown's

"Directory of American Cement Industries;" and number three is taken from Professor I. O. Baker's "Roads and Pavements." They seem to have the same general origin.

TABLE 7.
Materials used in Coloring Mortars.

Color.	Mineral.	Pounds of Color to 100 Pounds Cement.		Pounds Color to Barrels Cement.
		1	2	3
Gray	Germantown Lamp Black	$\frac{1}{4}$	$\frac{1}{2}$	2
Black	Manganese Dioxide	12	.....	48
Black	Excelsior Carbon Black .....	.....	2	.....
Blue	Ultramarine	5	5 to 6	20
Green	Ultramarine Green	6	6	24
Red	Iron Oxide	6	6 to 10	24
Bright Red.	Pompeian or English Red	6	6	24
Sandstone Red.	Purple Oxide of Iron	6	.....	24
Violet	Violet Oxide of Iron	6	.....	24
Brown	Roasted Iron Oxide or Brown Ochre	6	6	24
Yellow or Buff	Yellow Ochre	6	6 to 10	24
White	Lime, White Sand and Marble, also a Mixture of Lead and Zinc Salts with Calc Spar will give very light surfaces.			

The color is mixed in various ways. In concrete walks it is sometimes sprinkled on the top and troweled into the surface. This does not give an even color nor does it last as well as when thoroughly incorporated with the sand and cement. It is sometimes added to the sand and thoroughly mixed dry, then the cement and finally the water is added. The best method is to mix the coloring matter and cement dry, and use it thereafter as so much cement. Strength is gained and expense saved by using the colored cement for the surface coating only, not exceeding one inch in depth with the colored mortar used.

The effects in the red and brown sandstones are imitated so perfectly that it requires close inspection to detect the artificial from the natural stone. The artificial stone, however, is more durable and stronger than the natural stone.

HAIR CRACKS OR SUN CRACKS.

The surface of concrete sidewalks, and the smooth finished surfaces of other cement or concrete structures, frequently exhibit a network of fine cracks variously called sun-cracks, hair-cracks, veins and crazed work.

There appears to be a variety of opinions as to the cause of these veins or cracks. A summary of the answers received to the question "What causes sun-cracks or hair-cracks?" may not be out of place. These answers were received from experienced cement workers, engineers and cement manufacturers. Twelve gave as a reason, that the surface coating was too rich in cement. One, that too fine sand caused the trouble, bringing too much cement to the surface. Three, that over troweling was

to blame, and one or two of these said that the troweling brought an excess of cement to the surface. Three said that it was caused by troweling after initial set. Two that rapid evaporation or drying out of the surface caused the cracks. One claimed that hydration of free lime and the absorption of carbon dioxide caused the fine rupturing of the surface. One man said that "if the surface be troweled hard just at beginning of initial set, until all the water is taken up, there will be no hair-cracks."

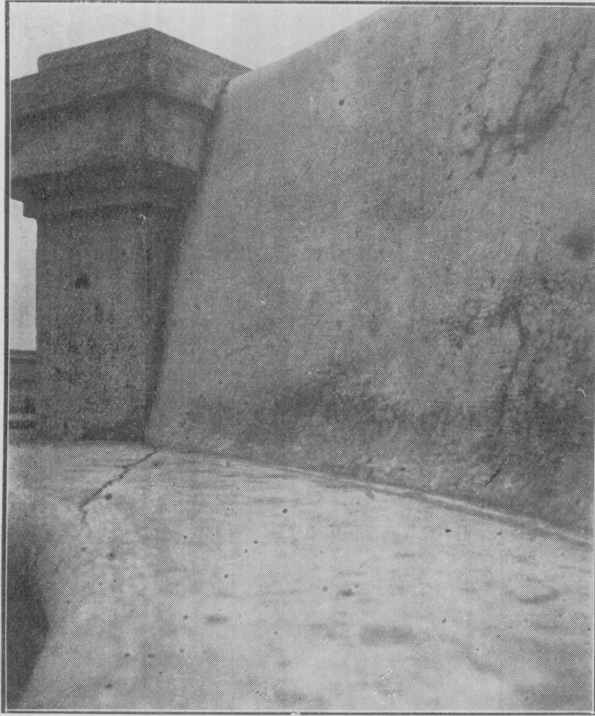


Fig. 3.—Parapet of the Y Bridge at Zanesville, Ohio, Showing Hair Cracks and Surface Corrosion.

A translation from L. Gollinellis* says: "Hair-cracks appear as fine lines on cement work which has stood some time. They are especially to be noticed on cement which has lain in the open air, and are due to frequent changes between wet and dry conditions. Hair-cracks and shrinkage cracks occur chiefly when pure cement, or mortar too rich in cement, is used. They may be certainly avoided by the use of sufficient sand and suitable treatment of the work."

Mr. W. D. Lober, Secretary of the Vulcanite Portland Cement Company of Philadelphia, says of smooth finished concrete work: "The troweling brings the water to the surface and also the fine particles of cement which are carried with the water and makes the surface practically neat

**Das Kleine Cement-Buch. Eng Record*, May 12 and June 2, 1900.

cement. If the surface is left in the wet condition and not protected from air and sun, it will dry out very quickly and in common with other materials in a moist state when drying in this manner it will crack."

Figure 3 shows the initial appearance of hair-cracks as illustrated upon the parapets and corner posts of the Y bridge at Zanesville. Figure 4

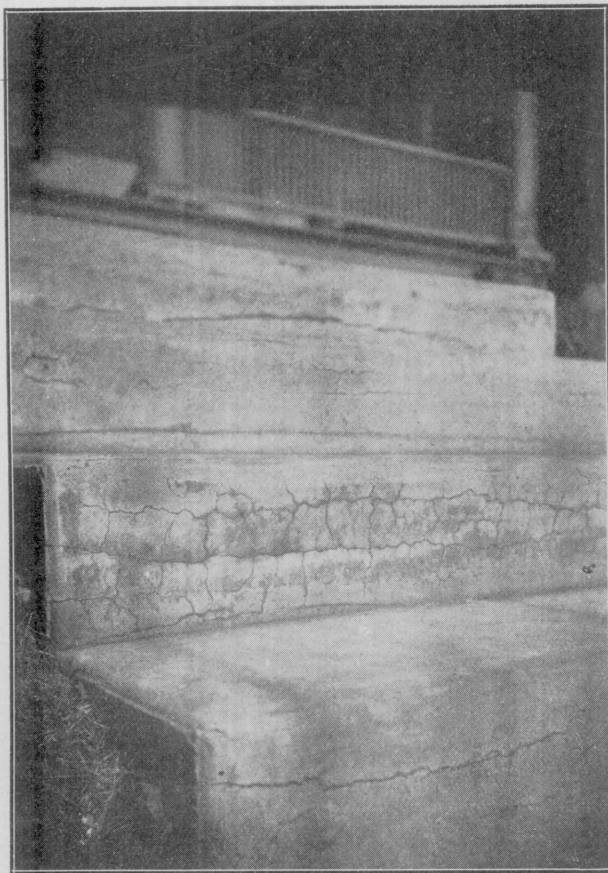


Fig. 4.—Concrete Steps, Showing Developed Hair Cracks.

shows the approaching dissolution of some concrete steps affected with hair-cracks. These steps have been down twenty-two months.

As the fine sand and over-troweling both develop an excess of cement at the surface, there are really 16 answers favoring over-rich mortar as the cause, with 6 answers scattered between troweling after initial set, rapid drying, and the after hydration of excess free lime.

It has been the writer's opinion based upon several years of observation both of the construction and the wear of cement walks, that such cracks are caused by the expansion and contraction of the immediate

surface where it is composed of a mortar too rich in cement. In some cases this effect has been particularly aggravated by troweling more cement to the surface. The neat cement film has a different coefficient of contraction than the mortar of sand and cement and causes fine cracks on the surface in setting. This effect is seldom seen in surfaces where coarse sand has been used. One very successful walk builder in Peoria, Illinois, said that while specifications usually called for a top coat of 1 cement to 1 sand, he could do better work with a mortar of 1 cement to $1\frac{1}{2}$ or 2 sand, usually using a 1 to $1\frac{1}{2}$ mortar. He has the reputation of being one of the safest and best walk builders in Central Illinois.

In and around Chicago the specifications for cement walks usually call for the top coating to be of one part Portland cement and one part of clean coarse sand or torpedo gravel, which is a fine uniform gravel, slightly coarser than the standard crushed quartz used in cement laboratory tests. The walks, as a rule, around Chicago, are durable, well made walks, and seldom show veins or sun cracks.

The concrete walks in the Ohio State University campus show veins in many places and the writer has been watching their development for over two years. At first, fine hair-cracks appeared upon the surface of the walks, then after some time a deposit of brownish or slate colored material appeared along the hair-cracks and the cracks were more marked, became wider and more continuous. The deposit became from $\frac{1}{8}$ to $\frac{1}{4}$ inch in width and of appreciable thickness. After two or more years the cracks open much more rapidly, as the frost seems to obtain better leverage.

Samples of this brown deposit were analyzed for the writer by Mr. A. V. Bleining, chemist in the Department of Ceramics, with the following results:

	Per cents.
Soluble matter	7.61
Silica	33.06
Alumina	3.68
Calcium Oxide	37.98
Magnesium Oxide	7.02
Losses, black organic matter—sulphur, alkalis, etc.....	10.65
Total	100.00

The soluble matter analyzed as follows:

	Per cents.
Alumina	1.07
Calcium Oxide	1.84
Magnesium Oxide	0.06
Alkalies, etc.	4.64
Total	7.61

The mortar in the concrete next the veins was analyzed and showed,

	Per cents.
Magnesium Oxide	1.15
Sulphuric Anhydride	1.53

The results show a high content of magnesium and calcium sulphates, both of which are injurious to concrete.

Mr. Bleining says that the water leaching through the concrete brings to the fine hair-cracks these soluble alkalies, calcium and magnesium sulphates, and they are deposited along the cracks upon evaporation, together with other chemicals which form insoluble compounds. The leaching process opens the concrete for still further leaching and the concentration of the chemicals induces greater changes and thus the damage increases.

Of course in winter the water, freezing in the cracks, expands them, and the stone having been weakened by the leaching chemicals is ready to go to pieces. The organic salts and sulphuric acid aid greatly the solubility of the mortar materials and these chemicals may be greatly augmented from the soil and particularly from the cinder foundations.

Poorly tamped or porous concrete will also be more easily attacked in this manner.

LIME IN CEMENT MORTAR.

Lime is frequently used in cement mortar for various reasons. Masons claim that cement mortar works harsh and brittle, and that the addition of lime paste to the mortar "gives it body" and makes it "work smoothly" under the trowel. Lime paste is frequently added to cement mortar to cheapen it; the claim being made that lime paste up to 25 per cent. of the cementitious material used may be added without perceptibly weakening the mortar. General Gilmore says that lime paste equivalent to one-half or three-fourths of the volume of cement may be used without producing serious deterioration in the mortar. Lime paste is frequently added to cement mortar to make it impervious. Others have added 10 to 20 per cent. of cement to lime mortar in order to strengthen it.

In 1891, the writer carried on a series of tests to prove some of these claims for lime-cement mortars. The tests were carefully made in the laboratory of the University of Illinois and covered a period of five months. The mortar used was composed of one part cement to two parts of clean coarse sand of standard sized grains. The cement was composed of various parts of lime and a natural cement, ranging from all natural cement to all lime paste. A parallel set of tests was also conducted with Portland cement and lime. The tests were made to find the adhesive and cohesive strength of such mortars and compare them with the tensile strength ordinarily found by making the mortar into briquettes and breaking them. Bricks were laid crosswise to each other and cemented together with these mortars and their strength or resistance to breaking apart was obtained. Eight hundred of these adhesive tests and 160 of the ordinary tensile tests were made with each kind of cement. Table number 8 shows the proportions of lime, cement and sand used in parts by volume.

TABLE No. 8.

Proportion of Lime, Cement and Sand Used in Mortars.

Ref. No.	Lime Paste, in Parts.	Cements, in Parts.	Sand, in Parts.
1	0	10	20
2	1	9	20
3	2	8	20
4	4	6	20
5	6	4	20
6	8	2	20
7	9	1	20
8	10	0	20

TABLE NO. 9.

Adhesion Between Mortar and Brick.

Cement, per cents of	Composition of Cementitious Material.							
	100	90	80	60	40	20	10	00
Lime paste, per cents of	00	10	20	40	60	80	90	100
Order of Making.	5	6	4	2	1	3	7	8
Age in Days.	Pounds Per Square Inch.							
1	6.1	3.1	2.9	4.0	3.6	2.6	2.7	2.0
2	7.4	9.3	4.5	5.1	3.5	2.9	3.5	2.6
3	6.7	10.1	4.6	4.4	5.0	2.5	1.9	2.9
4	8.5	11.4	5.0	5.6	5.7	3.7	2.6	2.6
5	7.4	15.1	5.8	5.9	6.5	2.9	3.7	1.9
6	.....	16.0	5.1	7.0	6.6	3.6	3.1	2.3
7	8.4	16.9	5.2	7.1	7.0	3.6	3.1	2.3
14	19.4	21.5	12.0	8.8	9.0	6.3	4.4	5.2
21	20.0	24.5	22.9	12.5	8.3	8.0	6.3	5.8
28	27.1	24.4	23.6	15.2	8.7	8.9	6.9	7.3
35	30.5	26.4	28.7	15.5	16.9	10.7	6.4	10.1
42	35.7	31.3	27.6	15.1	9.5	8.1	8.5	12.1
49	36.2	35.8	32.9	16.2	13.2	7.5	7.6	13.9
56	33.3	31.2	38.2	21.7	13.4	9.0	10.8	15.2
63	40.5	38.4	35.1	24.8	16.5	11.6	11.5	.....
91	42.0	41.5	35.9	22.3	21.5	10.7	11.1	12.2
119	44.7	39.1	43.9	22.6	15.1	12.6	11.7	.....
147	47.2	51.3	36.8	25.0	15.7	10.4	.....	.....

Table No. 9 shows the results for adhesion with the natural cement for ages varying from one day to five months.

Diagram No. 1 shows the same clearly in a graphical form.

Diagram No. 2 presents the same in still another form.

Table No. 10 shows the cement, sand and lime used in pounds, with the cost of the lime and cement.

DIAGRAM I

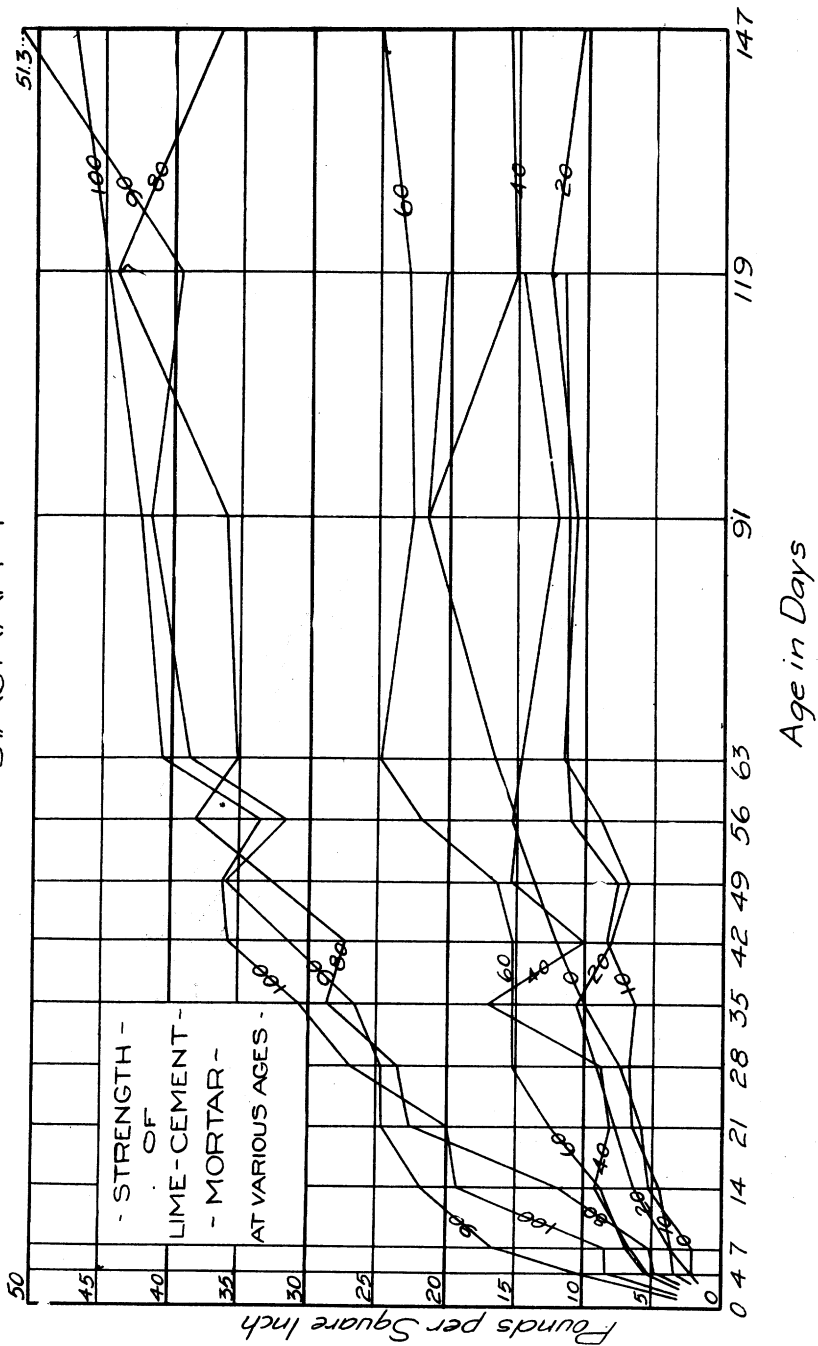


DIAGRAM 2

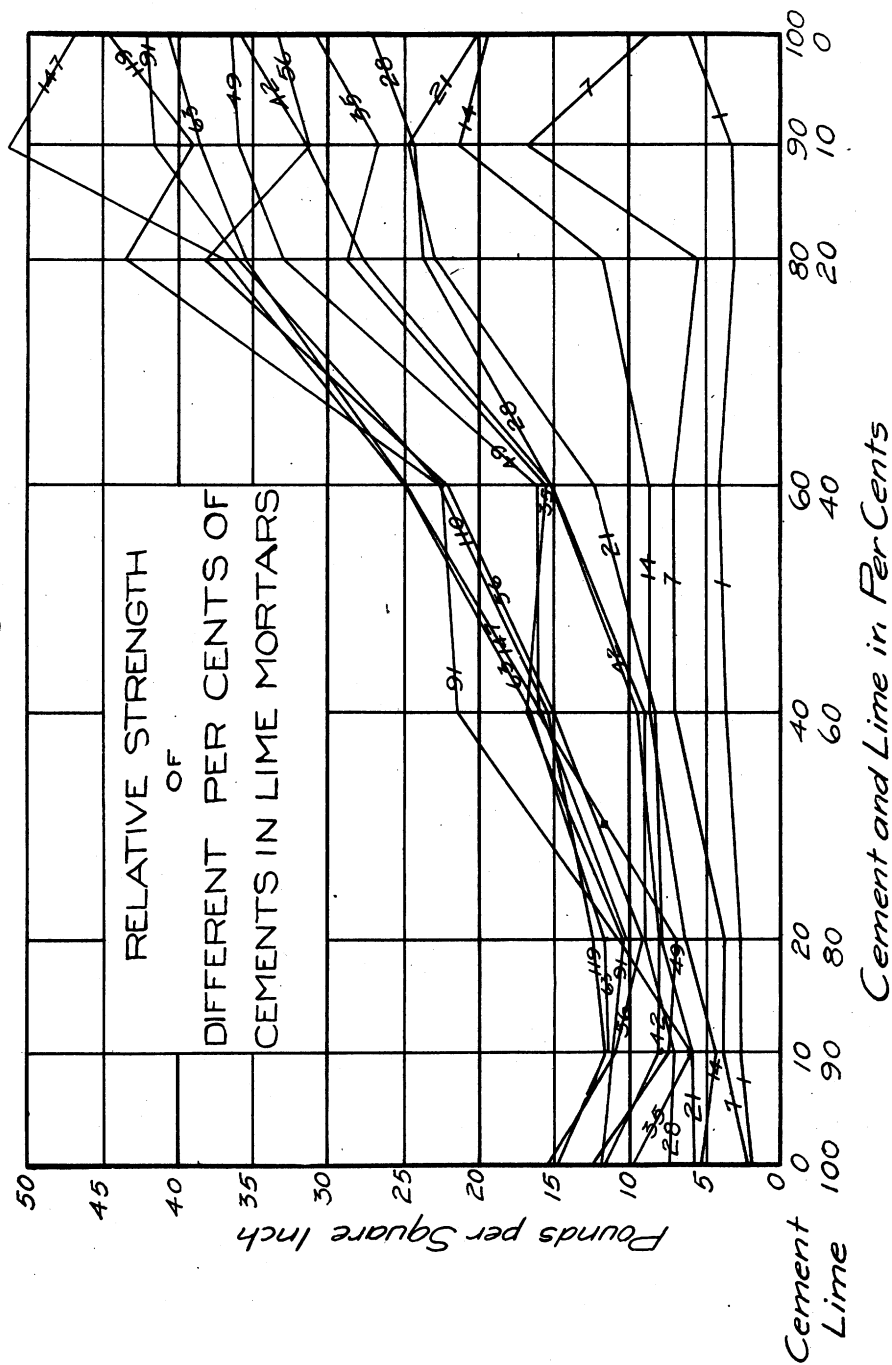


TABLE No. 10.

Proportions of Sand, Cement, Lime, and Water in Pounds with the Cost of the Lime and Cement. Proportions by Volume.

Pounds of				Total weight of Water.	Values given in Cents.			
Sand.	Cement.	Lime.	Water in Mortar.		Cost of		Amount saved.	
					Lime.	Cement.	Total.	Per Pound of Cement.
9	2.85	.00	2.31	2.31	.000	1.075	.000	.000
9	2.56	.41	2.17	2.47	.029	0.968	.078	.027
9	2.27	.83	1.75	2.36	.057	.860	.158	.055
9	1.70	1.74	1.21	2.44	.115	.645	.315	.110
9	1.14	2.47	.92	2.68	.172	.330	.573	.201
9	.57	3.29	.25	2.60	.229	.215	.631	.221
9	.28	3.71	.20	2.85	.258	.107	.710	.249
9	.00	4.12	.00	2.92	.287	.000	.788	.276

The conclusions reached were, first, that 10 or 20 per cent. of lime paste added to cement mortar did not materially affect its strength, but cheapened it from $2\frac{1}{2}$ to 5 per cent. of the cost of the cement. Second, that any greater per cent. of lime paste added, rapidly decreased the strength of the mortar without an adequate reduction in the cost. Third, that adding 10 or 20 per cent. of cement to lime mortar weakened instead of strengthened the mortar and increased the cost. The investigation also indicated that the addition of a small percentage of lime paste to cement mortar, or of cement to lime mortar, did reduce the harshness of the mortar in the one case and the stickiness of the mortar in the other, causing it to work much easier under the trowel, and from that point of view was a benefit to the mason.

TABLE No. 11.

Relative Strength of Mortars in Briquettes and in Joints.

Mortar Composed of 2 parts Sand and 1 part Cement and Lime Paste.		Age in Days.	Cohesion in Pounds per Square Inch.		
Composition of the Paste.			Stored in		
			Air.		Water.
			Between Brick.	In Briquettes.	In Briquettes.
Per cent. of Cement.	Per cent. of Lime Paste.				
100	00	7	9.9	29.6	10.1
100	00	28	27.1	38.6	49.3
100	00	35	30.5	40.7	23.4
100	00	63	40.5	.....	.....
100	00	77	.....	34.7	109.7
80	20	42	19.1	27.8	65.1
40	60	28	8.7	15.6	.....
10	90	28	6.9	15.1	.....

The comparison between the mortar placed between the bricks in as nearly the same manner as a mason would lay brick masonry and the mortar molded into briquettes is shown in table number II.

A similar series of tests upon the same cements mixed with lime paste, the mortar being formed by using the materials in proportions by weight instead of volume, is now being carried on by students of the Ohio State University. So far as the tests have proceeded they seem to corroborate the tests given above.

PLASTER.

An important use for cement mortar is in the form of plastering or coating surfaces such as the impervious coatings for retaining water in cisterns, reservoirs and tanks, or the outer coating used to prevent water entering sub-surface areas as in basements, manholes and conduits. It is also used upon the exterior surfaces to protect them from the destructive influences of the elements, and upon the inner walls and ceilings of houses to give a hard, smooth finish. Care should be exercised to proportion the sand and the cement so that the mortar shall be impervious by having all the voids filled. A Portland cement is best for this purpose. Its proportions should be about one part cement and one and three-quarters to two and one-half parts of clean sand, the proportion varying according to the voids contained in the sand.

The Buckeye Portland Cement Company publish the following:

"For water tight work, as cisterns, etc., in coats $\frac{3}{4}$ of an inch thick, the following proportions of Portland cement-lime-mortar can be used with safety and economy."

TABLE 12.
Proportions in Portland Cement-Lime-Mortar.

Portland Cement.	Sand.	Lime Paste.
1 part	2 parts	0.5 part
1 "	3 "	1.0 "
1 "	5 "	1.5 "
1 "	6 "	2.0 "

"Mortar made with five or six parts sand to one of Buckeye Portland cement is good enough as far as strength is concerned, but is then too 'poor,' 'short' or 'brash,' and does not adhere sufficiently to the stone and brick.

"The addition of slacked lime in small proportions makes the mortar 'fat,' 'rich' and pleasant to work.

"It greatly increases its adhesiveness and density, and, contrary to general belief, also adds to the strength of all such mixtures.

"Any greater or any less proportion of lime to the mixture given will lessen the density, the tensile strength, the crushing strength and the adhesiveness. This lime paste or slacked lime is more than half water.

TABLE 13.

Table of Proper Proportions for Ordinary Purposes.

Portland Cement.	Sand.	Lime Paste.
1 part	5 parts	0.5 part
1 "	6 "	1.0 "
1 "	8 "	1.5 "
1 "	10 "	2.0 "

TABLE 14.

Amount of Sand, Portland Cement and Lime Putty
Needed to Lay 1,000 Bricks.

Joint.	Proportion of Mortar to the Brick.	Bushels of Sand.	Bushels of Cement.	Bushels of Lime.
$\frac{1}{8}$ in.	1-9	3.8	.64	.64
$\frac{1}{4}$ "	1-4	9.6	1.6	1.6
$\frac{3}{8}$ "	3-10	12.5	2.1	2.1
$\frac{1}{2}$ "	1-3	15.2	2.5	2.5

"Three and one-third bushels of Buckeye Portland cement in each barrel.

"One barrel of above described Buckeye Portland cement mortar will lay 2,000 bricks with $\frac{1}{4}$ inch joints."

The following is taken from the "Directory of American Cement Industries."

TABLE 15.

Volume of Mortar in a cubic yard of Masonry.

	Cu. Yds.
"For brick work, $\frac{1}{8}$ inch joints.....	0.15
For brick work, $\frac{1}{4}$ inch joints.....	0.25
For brick work, $\frac{1}{2}$ inch joints.....	0.40
For ashlar, 20-inch courses.....	0.06
For squared stone masonry.....	0.20
For rubble masonry.....	0.25
For concrete, broken stone.....	0.55"

Mr. F. P. Van Hook, in an article in Municipal Engineering Magazine telling how to prepare a Portland cement wall plaster, says:

"Portland cement mortar should be made as follows: Take good double strength lime, and slake in plenty of water. Do not stir the lime only enough to keep the large lumps from burning. It should stand a week or ten days before using. Put in $2\frac{1}{2}$ bushels of good clean hair to two barrels of lime; when ready to commence plastering, take one barrel of a good standard

brand of American Portland cement to three barrels of lime. First, mix the Portland cement with four parts of sand, mixing the sand and cement thoroughly. Second, the lime mortar should be sanded to the right consistency to make a good, rich mortar. Third, mix the sanded cement with the lime mortar as it is used. It will take a very little mixing to make a fine tough mortar."

CEMENT STUCCO FOR WALLS.

Mr. Van Hook also gives the following instructions for cement stucco:

"First coat, one-half inch thick. For best results, the wall should be furred off with spruce lath put on vertically, 12 inches apart and well nailed. On these fasten firmly, expanded metal lath. Add fibre to the mortar for lathwork. Wet thoroughly the surface to be plastered. Mix one part of non-staining Portland cement with two parts medium sand, one part fine sand and one-half part lime flour. When this coat has set hard, wet the surface thoroughly and apply the second coat with a wooden float.

"Second coat, one-quarter inch thick. Mix one part cement as above, one part fine sand and two parts medium sand or crushed granite. Before the second coat has set hard, it may be jointed to present the appearance of stone work. A small addition of lime flour increases the adhesion of the mortar.

"The finished surface should be protected for at least two weeks with canvass curtains or bagging saturated with water.

"Defects are liable to appear on cement plastered walls when (1) too much cement is used; (2) not applied with sufficient moisture; (3) not troweled sufficiently; (4) not protected from variations in temperature and drafts of air."

Cement manufacturers publish the following table of areas covered with Portland cement mortars of various proportions per barrel of Portland cement used:

TABLE 16.
Showing Area Covered by Mortar Produced from One
Barrel Portland Cement.

Composition of Mortar.	Thickness of Coat.	Sq. Ft. of Area Covered.
1 Cement 1 Sand	1 inch	67
	$\frac{3}{4}$ "	90
	$\frac{1}{2}$ "	134
1 Cement 2 Sand	1 "	104
	$\frac{3}{4}$ "	139
	$\frac{1}{2}$ "	208
1 Cement 3 Sand	1 "	140
	$\frac{3}{4}$ "	187
	$\frac{1}{2}$ "	280

The Buckeye Portland Cement Company print a useful table showing various data in reference to plastering cisterns, which table is here inserted:

TABLE 17.

Showing Capacity, Quantities of Excavation, Stone and Brick Lining and Plastering in Cisterns of various diameters, for each foot of depth.
Also number of bricks and amount of plastering in bottom.

Diameter in feet.			For Each Foot Depth.				Bottom.	
	Capacity Gallons.	For this Column use diam dig g.	For these Columns Use Diameter in Clear of Lining.				Use diam. of digging	Use diam. in clear of Lining.
	For each ft. depth.	Cub. yds. of digging.	Stone lin'g 1 foot thick, 25 cub. ft.	No. bricks in lining— one thick.	Sqr. yards plastering.	Bricks in Bottom.	Plastering in bottom square yds.	
5	146	.73	.75	230	1.74	148	2.18	
6	211	1.04	.88	275	2.09	215	3.14	
7	288	1.42	1.00	320	2.44	292	4.27	
8	377	1.86	1.13	365	2.79	382	5.58	
9	476	2.36	1.26	410	3.14	483	7.06	
10	587	2.91	1.38	460	3.49	596	8.72	
11	710	3.52	1.51	500	3.84	722	10.56	
12	846	4.19	1.63	550	4.19	859	12.56	
13	992	4.92	1.76	590	4.54	1008	14.74	
14	1152	5.70	1.88	640	4.89	1170	17.10	
15	1325	6.54	2.01	680	5.24	1343	19.63	

For the number of hundred pounds of cement needed for a half inch plaster coat, divide the square yards by 15 if half cement and half sand or .5 if a third cement and two-thirds sand.

CONCRETE MOLDINGS AND BASE-BOARDS.

In the Alexian Brothers' Hospital, Chicago, * marble concrete, called "art marble," is used for the floors, base moldings and stairway treads and risers. No wood or plaster was used within 6 inches of the floors. All base moldings were made continuous around corners and at door openings. All exposed angles were rounded and the marble surfaces polished.

The tread and riser for each step was made in one piece. The foot of each riser was recessed into the top of the next lower tread so as to make but one tightly fitting joint for each step. Figure 5 shows the method of construction. Such sanitary construction should be a part of all public buildings, but especially those used for hospital purposes.

*Eng. Record, Feb. 3, 1900.

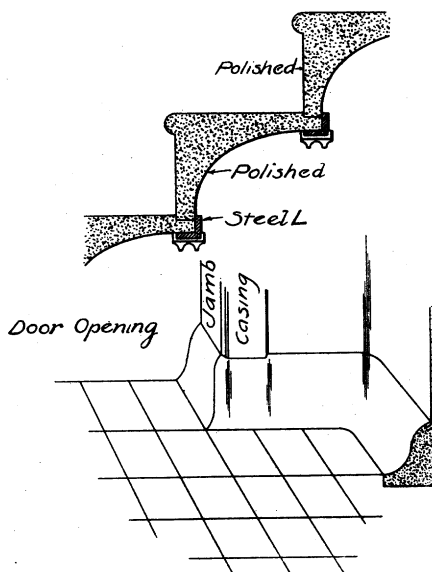


Fig. 5.—Illustrated Use of Stairway and Baseboard, Alexian Bros.' Hospital, Chicago, Ill.

FILLERS.

Cement mortar or grout, a very thin liquid mixture of cement, sand and water, is frequently used to fill the joints in street paving. "Murphy's Grout Filler" was among the first so used. This is a patented mixture of Portland cement, ground slag and sand; the claim is made that the slag gives both strength and impermeability to the mortar.

Portland cement two parts, with fine sand one part mixed with sufficient water to make a fluid grout, makes a good filler for both brick and wood paved streets. Such a filler is impervious, durable, and gives good support to the blocks. The strongest objection to its use with brick pavements is its unyielding character which does not allow for expansion. Frequently in hot weather, when expansion takes place, in brick paved streets having grout filling, the pavement will arch away from the foundation, causing the streets to rumble under traffic. Because the bricks are unsupported except by arch action, they are apt to yield under heavy traffic and long cracks or ruts appear in the street allowing water to reach the foundations, thus quickly destroying the pavement. This danger can be prevented, however, by putting in longitudinal and transverse expansion joints of asphaltic or coal tar cements.

GROUTING.

Mr. Wm. J. McAlpine* says in substance, long experience proves that tight work can only be made in grouting masonry when neat cement

**Eng. News*, April 17, 1902.

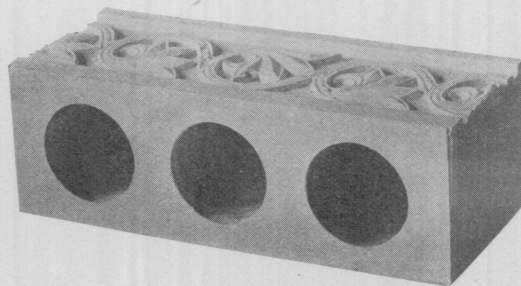


Fig. 6.—Ornamental Block of Litholite.

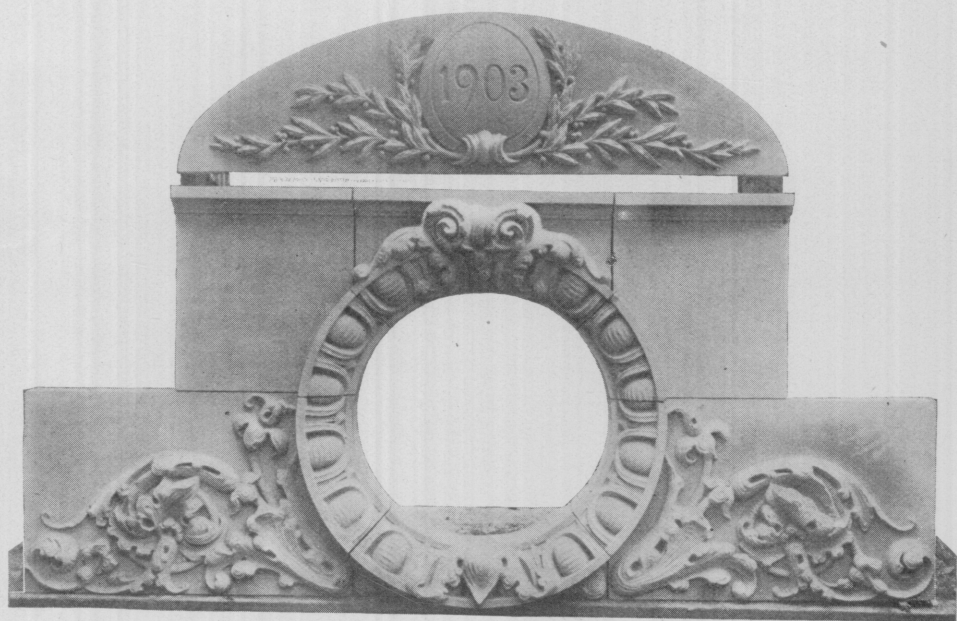


Fig. 7.—Ornamental Pieces Designed for a Library Building. Stevens' Cast Stone or Litholite.

is used. If sand is used with cement, it separates and settles, filling and blocking the channels, and preventing the cement from reaching the lower cavities in the masonry. The result is that the lower portion of the masonry has many unfilled voids, then comes a layer having the interstices filled with sand and the top layer is filled with neat or nearly neat cement grout.

Nearly forty years ago a commission of Government Engineers of whom Major R. E. Lee was one, built a wall and carefully grouted it with sand and cement grout. When the wall was torn down the results claimed by Mr. McAlpine were substantiated.

ORNAMENTAL WORK.

For many years in Europe, and for the last few years in this country, the use of cement mortar for ornamental work such as ceiling and wall panels, capitals, gargoyles, bases, stucco work, mosaic and tile work has been rapidly increasing. Such work is as lasting as cut stone, and far cheaper, because cast iron or wooden molds can be used over and over again in producing panel work or duplicate parts. Molding sand is also used for the forms.

Portland cement castings are much more durable than many of the building stones, and are much easier repaired in case of damage. Fire practically makes no impression upon them, while most natural stones would be completely destroyed by the combined effects of fire and water.

The mortar for this class of work should be composed of one part Portland cement and two parts of sand graded in size of grains, so that the voids in the sand would be proportionately small, and an even grain result in the artificial stone thus manufactured.

The Stevens Cast-Stone Company, of Chicago, manufacture an artificial stone called Litholite, illustrations of which will furnish an idea of what can be done in cement casting. One form of this stone is made by crushing any natural stone to granular form, mixing it with Portland cement and as explained by Mr. Stevens himself,

"by mixing materials so thin that we are able to run it through a rubber hose into the molds, we have produced a stone that meets the approval of architects and builders. Now, if we had no way of getting rid of this surplus water, we could not produce a first-class article, but we cast it in a porous mold, allowing the surplus water to be absorbed into the mold before initial set takes place. To produce a perfect crystallization, the stone should have more water as soon as the initial set has taken place. This is supplied through the porous mold, but at no time does the cement receive more water than is required for a perfect crystallization. Induration by absorption through a porous mold was so novel and new that we were cited to no patents with which we interfered."

"One of the worst problems has been to overcome the hair checking from appearing in cement work. To the best of our knowledge there are several causes for this hair checking. One cause is fresh cement, especially

if there is any free lime in it, other causes being the workmanship. Cement mixed not stronger than one to three or four of sand is not liable to hair check, and if the stone is well seasoned before exposing to the weather, it will not hair check."

In reference to the cost of the stone, Mr. Stevens, writes,

"We can get from one barrel of cement twenty-four pieces of stone 10 by 12 by 30 inches, or 60 lineal feet. With Portland cement selling at \$2.40 per barrel, the cement in each block would cost ten cents; the other material being sand, gravel and crushed stone, the cost of these would depend entirely upon the locality."

He says that one man will make from 30 to 40 blocks per day of the size mentioned, and that with crushed stone at 85 cents per yard and sand and gravel at \$1.25 per yard, they are making hollow trimmings, porch columns, etc., at 26 to 35 per cent. of the cost of natural stone work. His process for stone is shown by the sketch and patent explained below:

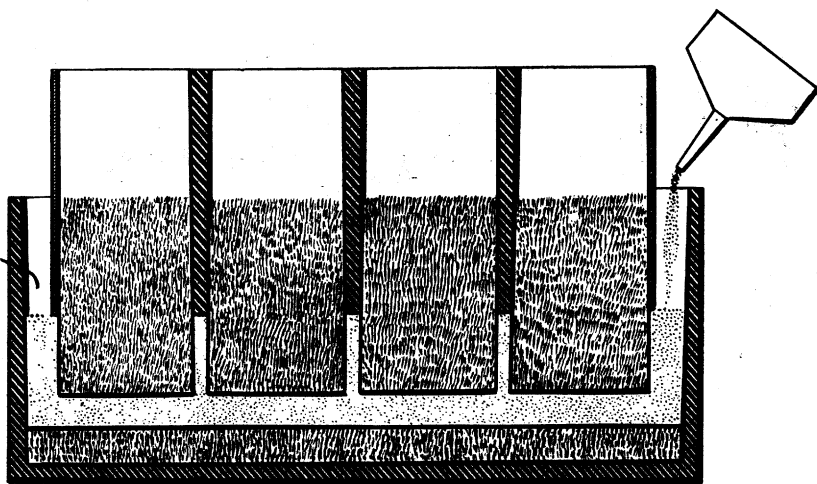


Fig. 8.—Illustrating the Method of Casting Litholite.

EXTRACT FROM PATENT SPECIFICATIONS.

Process of Making Artificial Stone. Charles W. Stevens, North Harvey, Ill.
American Patent No. 699,588.

The process of making artificial stone, which consists in forming a mold containing a plurality of dry-sand cores, said cores being laterally supported by removable parting-boards and separated by parting-boards so disposed as to provide a space between the opposing faces of said parting-boards, in then pouring wet artificial-stone compound into said mold around and between said parting-boards, in withdrawing said parting-boards while the stone compound is still sufficiently plastic to flow into the space previously occupied by the parting-boards, and in then allowing the compound to set.

The illustration, Figure 9, shows a beautiful monument which Mr. Warren S. Cushman, the sculptor, designed and which was erected at Woodstock, Ohio, in memory of the soldiers and sailors of the Civil War.

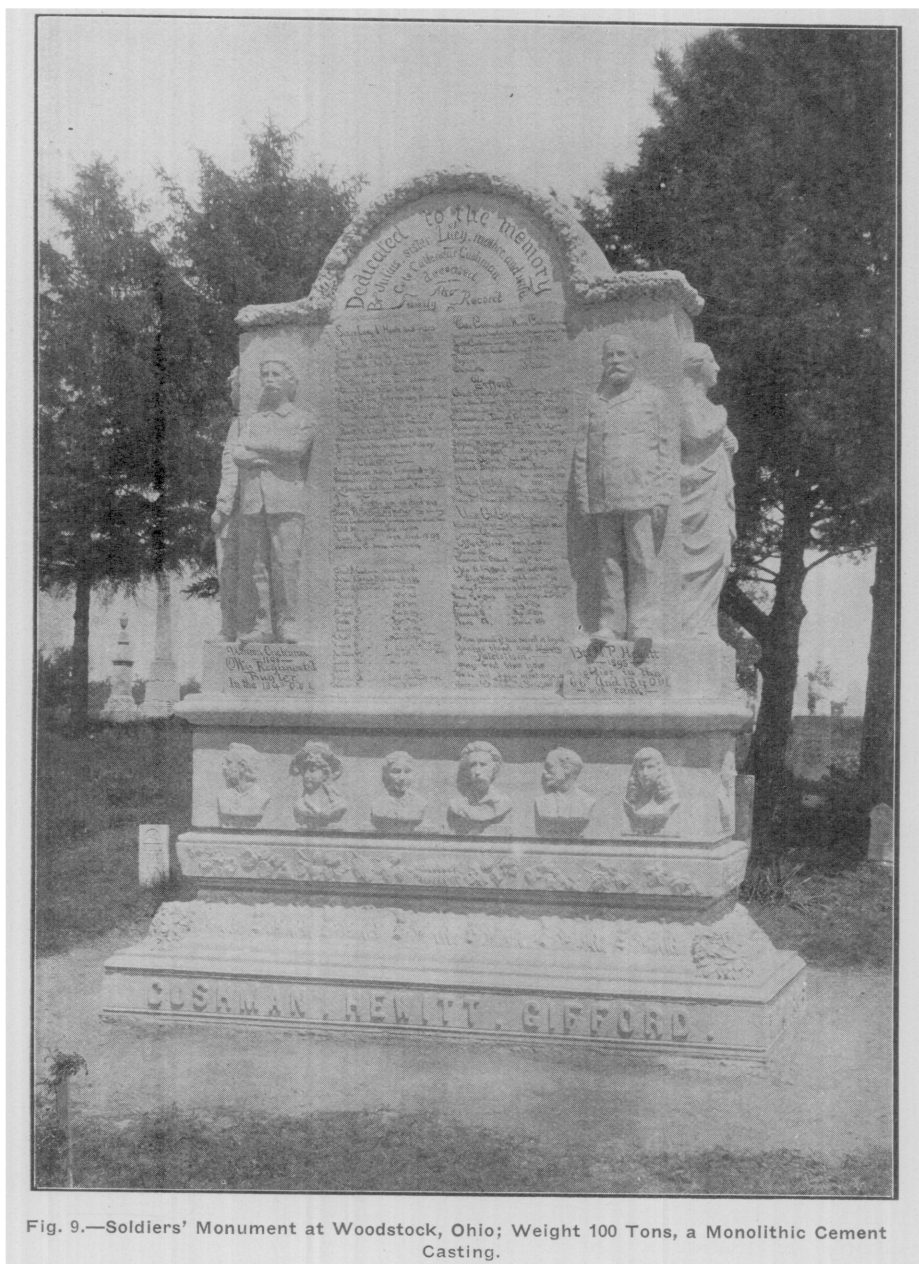


Fig. 9.—Soldiers' Monument at Woodstock, Ohio; Weight 100 Tons, a Monolithic Cement Casting.

This monument is a monolith, cast where it stands from Buckeye Portland cement. It is 26 feet high and 14 feet square and weighs about 100 tons.

Mr. Cushman has made a careful study of Portland cement in connection with outdoor monumental work with a view of finding something more durable than marble and granite, and he believes that Portland cement fills his desires in that direction.

ROPE MOLDING.

Among other ornamental features, the Aberthaw Construction Co. of Boston, now make a cast stone rope molding in two styles, smooth and rough finish. Like other ornamental designs this can be made in any color.

MOSAIC WORK.

For mosaic work, small colored pieces of encaustic tile, glass, marble, onyx, ornamental stones, or previously hardened pieces of colored cement are arranged in various patterns and cloth netting is glued or cemented over the face with some soluble cement. These flexible sheets of mosaic design called "Corded Ceramic Mosaic" are then ready for the bed stone of cement mortar. This bed plate is made of 1 part of Portland cement and 2 parts of sand, mixed quite wet. The sheet is then laid upon the fresh mortar and pressed down into it until the mortar has risen between the pieces up to the level of the sheet; the sheet is then soaked loose, the position of the pieces adjusted so as to secure uniform mortar joints and the plate is then allowed to set. The trimming of rough surfaces or polishing, if any is required, is done when the cement has hardened. The mosaic plate is then ready for use. When complete, it is about two inches thick.

Terrazo work is that form of mosaic which is made by setting in a ground of colored mortar, small irregular pieces of colored marble, glass, tile or granite. Or, the pieces may be mixed with the mortar and the surface ground and polished after the mortar has set. A central design may also be bordered in this irregular work.

TILES AND FIGURED WORK.

Floor tiles, rivaling in appearance and durability those made of burned clay are made from cement. Generally this is done under the protection of patents covering the press or dies or some feature of the process. A single tile may be of one solid color, or may be made of several different colored cements accurately disposed in geometrical or other forms. These different colors are prepared by grinding the cement, coloring material and fine sand intimately together, dry. They are then filled into a cellular or honey-comb die, each compartment of the die receiving its charge of the proper color by means of perforated cards or

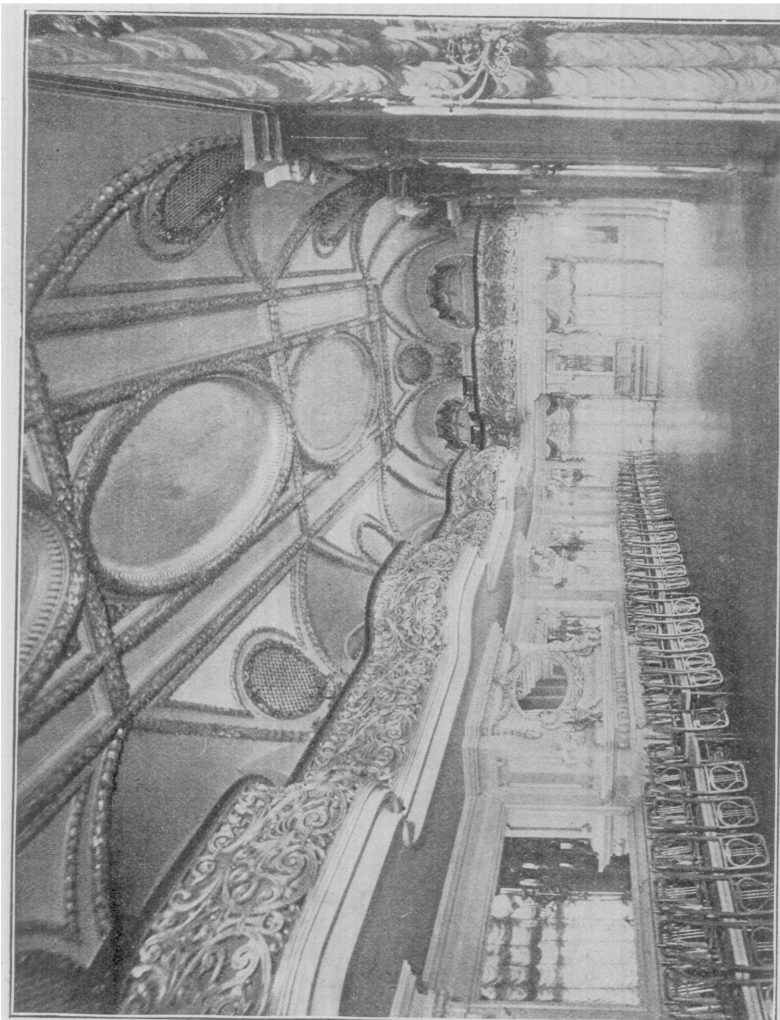


Fig. 10.—Ball Room, Hotel Flanders, Philadelphia, Pa., Showing Ornamental Effects
Produced with Woven Wire and Cement Plaster.

stencils which keep out all colors except the one being filled at the time. Each color requires its own stencil. When all the cells are charged, the comb is withdrawn gently, leaving the cement powder in little piles whose edges overlap one on the other. Without disturbing their positions, a mixture of coarse sand and cement, properly dampened, is now filled in on top of them until the die is full and stroked off level, when it is brought under a powerful press which compacts the loose material into a solid dense tile. The moisture from the damp backing penetrates and hydrates the dry cement composing the face so that in a day or so it has fully set. The tiles are placed on slabs of cement mixed with sawdust instead of sand; these are very porous and are kept damp so that they may furnish water as needed for the chemical process of setting the tile without softening its surface or causing the different colors to mix. In order to keep these colors clear and bright, and avoid the scum or whitewash, commonly found on cement surfaces, some chemical is generally used in the surface colors, or in the whole mass. This is generally kept secret, or patented, and is sold with the right to use the process. Magnesium fluoride is one of the best and commonest anti-scum chemicals in use for cements.

The tiles, when made and hardened, are used in laying floors exactly as clay tiles, being laid in a cement matrix or bed.

Imitation marble may be obtained by kneading and rolling together different colored mortars and pressing them into slabs which, after setting, can be ground and given a high degree of polish.

Figures 10 and 11 show what can be done with cement in ornamental lines.

FACINGS.

Cement mortar is used in facing concrete work. It is not put on as a plaster but the forms in which the concrete body is molded are so made that the outer surface, one to three inches in thickness, can be put in place and rammed at the same time as the body of concrete. This gives a smooth, finished appearance to the exterior and at the same time provides an impervious, durable surface. The mortar is usually made of one part cement to two or three parts of clean sand.

At first, the work was made of uniform texture throughout and the surface was coated with a plaster of neat cement, or of one part cement and one part fine sand. It was found, however, to be almost impossible to make a plaster coat permanently adhere to the body of the concrete mass which had become set before the plaster could be applied. The method of facing with mortar was then adopted. The latest practice, however, is to use a wet concrete in which all the voids are filled and which contains a slight excess of mortar. When the concrete is rammed, if a close tined fork with flat blades or a flat square backed shovel be forced down between the concrete mass and the form, it will force back

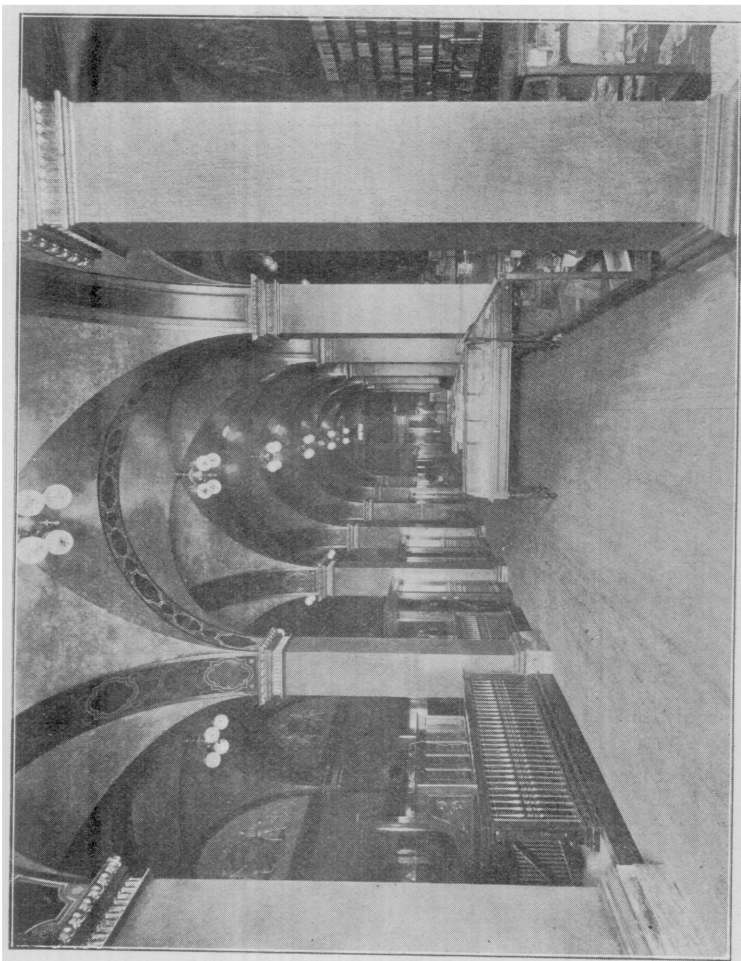


Fig. 11.—Main Corridor American Baptist Publishing Society Building, Philadelphia, Pa.,
Illustrating the Effect Obtained by Use of Cement With Furring and Wire Lathing.

the stone and coarse gravel and the excess of wet mortar will run next the form. Thus when the mass is set and the form removed the exterior will be smooth and waterproof. This method is cheaper than the two inch facing and equal in durability and appearance.

PROTECTION TO BRIDGE METAL.

Mr. J. M. Newhouse, carpenter foreman for the Columbus Terminal of the Pennsylvania railroad, has used Portland cement with oil and red lead to coat the metal work of the High Street Viaduct. A test section was coated early in 1900 and now after four years wear seems to be in excellent condition. Where it has been cut out for examination the metal is perfectly bright. The entire eastern section of the viaduct owned by the Big Four Railway Company was covered with this cement coating in 1900 and 1901 and is still in excellent condition. The outside of the eastern-most girder with the supporting posts show expansion cracks in the coating wherever the sun can strike the paint, but at no point does the coating seem to be loosened by this cracking. Upon cutting into the metal it does not appear to have sustained any corrosion. This coating was applied with trowels and is about $\frac{1}{4}$ of an inch thick. It required much care and time in spreading it, especially around the rivet heads. Small friction or troweling cracks would occur whenever hasty work was done. These cracks would have admitted water and allowed the rusting to proceed, therefore great care was used to put on a perfect coat. The steel work had been cleaned by the sand blast, and painted the year before, so that only hand cleaning was done before the mortar paint was applied. The cost of this coat, including the hand cleaning of the metal work and the cost of materials and applying them was eight cents per square foot.

The place is a particularly trying one on metal work, as the lower flanges of the girders are only about two feet above the smoke stacks of the passing engines. Practically all the traffic, passenger and freight, entering and leaving the Union station pass under this viaduct. Ordinary paints are cut out in a very short time and unprotected metal work soon corrodes through $\frac{1}{4}$ to $\frac{3}{8}$ inch members. If this cement coat lasts as it promises to do, it will be well worth the additional cost. The officials said that it cost from one quarter to two-thirds more than the paints usually used. The life of ordinary paints is not much over three years, and under the trying conditions of this particular place would not probably exceed eighteen months to two years at the longest.

Mr. Newhouse gives the following directions for the cement coat:

12 pounds of red lead.

32 pounds of Portland cement.

2 pounds of Japan.

Add sufficient linseed oil to make, when thoroughly mixed, a soft putty like mixture. Apply with a trowel, upon thoroughly cleaned metal.

Mr. Newhouse is experimenting with other mixtures which he thinks will be even better than the one given above. One of the railway officials said that he believed this would be cheaper than paint because of the greater length of life.

LININGS IN WARSHIPS.*

Cement mortar is used in certain places both upon the inner and outer steel skins of warships, particularly where it would be difficult or impracticable to prevent corrosion by paint alone. Cement mortar is also used in corners to prevent water standing in them; when a small space is inaccessible for cleaning or painting, it is filled solidly with cement mortar.

The use of cement is restricted to the minimum possible, and if satisfactory paint could be found for all locations, this mortar would not be used at all for protection of metal. The usual proportions are, 1 cement, 2 sand. For all metal protection it is applied as thin as possible, never over 3 inches thick.

CEMENT HARDENED QUICK SAND.

Mr. Robert L. Harris, M. Am. Soc. C. E., patented in 1891, a device for hardening quicksand by means of cement grout injected into the sand. Those who have ever attempted to carry on excavation or construction of any kind in quicksand know how discouragingly expensive such work is. Mr. Harris' method is to drive pipes into the quicksand to the required depth and from four to eight feet apart, and then by attaching pumps to alternate pipes and pumping in water under pressure circulation is begun between these pipes and the ones left open. After circulation has been established and sufficient sand removed, cement grout is pumped in to take the place of the displaced sand. As soon as the grout appears in the open pipes they are capped and the pumps are run until a strong pressure is obtained to force the grout into the surrounding sand and then left to stand until the cement has time to set. The pipes are then raised a foot or more and the operation repeated. Some tests were made at Providence, R. I., which seemed to indicate that it would prove quite successful under favorable conditions. It was especially recommended for work in coarse sand or gravel, also as an aid to prevent large flows of water into trenches.

In erecting a bridge over the Danube at Ehingen, Bavaria, in 1898, the method of pumping grout into water bearing gravel was used very successfully. One and one-half inch pipes spaced about 18 inches to 20 inches apart were driven to bed rock and grout forced in under pressure, the pipes then drawn up and the operation repeated. Where the gravel did not contain large quantities of sand the grout was found to have pene-

*Information received from Mr. W. L. Capps, Chief Constructor, U. S. N.

trated several meters, but when the sand was compact there was no result. In the mid-stream piers, sheet piling was first driven for the coffer-dams and then grout was injected into the gravel surrounding the sheeting, resulting in a perfectly water tight coffer-dam. The interior of one of the coffer-dams was also treated in this manner and it was found upon excavation that wherever the sand was not in compact beds, hard, well bonded beds of concrete existed so that only part of the interior had to be excavated.

The same method was successfully employed upon two other bridges in Bavaria in 1898 and 1900.

THE EFFECTS OF FREEZING UPON MORTAR.

Experimental work* carried on in 1895 by students of the Ohio State University, indicated that in natural cement mortars, frost affected them in about the ratio that they contained magnesium oxide, but this did not prove to be the case with Portland cements. In natural cement mortars freezing disintegrated the exterior to a greater or less depth, materially weakening the mortar, while in Portland cement mortars disintegration did not appear and the loss of strength was very much less.

Baker and Symonds, of Thayer School of Civil Engineering, Dartmouth College, came to the following conclusions after having made 7,150 tests, that freezing does not disintegrate Portland cement mortar but does disintegrate Rosendale cement mortars; that while it seriously damages the natural cement mortars, Portland cement mortars lose from 2 to 40 per cent. of their strength.

Tests in the Royal laboratory of Berlin in 1886, showed from 2 per cent. to 33 per cent. loss in different cements under different conditions when subjected to freezing.

W. W. McClay, M. Am. Soc. C. E., showed that the attempt to prevent the injurious effect of frost by heating the material and then using it in freezing temperatures was more hurtful than using the ingredients cold. In two sets of briquettes made of cement paste, one made at 45 degrees F. and the other at 100 degrees F., and treated exactly alike until broken, the strength of the heated mortar was found to be only 7 to 20 per cent. of that of the cold mixture. In case of a mortar of 1 cement and 2 of sand the strength of the heated mixture was only 30 per cent. of that of the cold mixture. This set of experiments, however, was upon one brand of cement only.

The Austrian Society of Engineers and Architects made some practical tests in the winter of 1892-93. They constructed 14 brick and stone walls, 3 feet, 4 inches long, 6 feet, 8 inches high, and 10 inches thick, using the following mortars: (1) common fat lime mortar. (2)

*Thesis of Frank Haas and John A. McGraw, on "Effect of Magnesia on the Strength of Cements when Subjected to Freezing."

Roman cement mortar. (3) Portland cement mortar. (4) One part Portland cement and two parts lime. (5) Cement and slag mortar. (6) A patent frost proof mortar.

All mortars were one part cementing material to two parts of sand. The walls were torn apart during the following summer. Their conclusions were: (1) That lime for a cementing material is entirely unsuited for cold weather construction. (2) That Roman cement can be used with fairly good results in brick masonry, but is not safe for rubble masonry construction in freezing weather. (3) That Portland cement mortar is not seriously affected in freezing weather and is especially good when used with salt. (4) That mortar mixed with warm water (77 degrees F.) showed about the same loss of strength as when cold water was used. (5) The frost proof cement and the Portland cement with salt showed very little loss of strength when frozen. (6) That dry brick and stone are necessary to safe construction under freezing conditions.

THE EFFECT OF HEAT UPON MORTAR.

M. Devol, of the Paris Testing Laboratory, made tests with briquettes of 1 cement to 3 of sand. They were allowed to harden in air from 24 hours to 30 days, and then placed in water at 177 degrees F. and kept from 2 to 7 days. Six brands of Portland cement were used. They resisted hot water at that age and gained about the strength in 7 days in hot water that they gained in cold water in 28 days. But when placed in hot water before being completely set, disintegration set in. Cements containing free lime when placed in hot water swelled, warped and cracked.

CHAPTER III.

THE USES OF CEMENT IN CONCRETE.

Cement was first extensively used to make concrete for foundations of large masonry structures. It may be well at this point to define concrete. Concrete is formed by a mixture of cement or lime mortar with any aggregate such as gravel, broken stone, cinders, or broken brick, the whole forming a solid conglomerate mass of stone. That formed with a cement mortar is sometimes called "beton." In this article, in speaking of concrete, that formed from natural or Portland cement will be understood unless otherwise stated in the immediate paragraph.

FOOTINGS AND FOUNDATIONS.

Concrete becomes of particular importance in footings and foundation work. In all properly designed structures the weight of the structure should be so distributed upon the foundation soil, that no unusual pressures can be developed. Undue pressure causes unequal settlement and therefore produces excessive and unknown strains within the various portions of the structure. With the usual rough stone masonry put in place for footing courses, it is almost impossible to obtain foundations having equal strength at all points and which transfer the weight of the structure uniformly to the soil beneath. On the other hand concrete can be placed in position by unskilled labor, with reasonable supervision, and become a homogeneous monolithic mass, capable of transferring the weight of the building very evenly to the subsoil foundation.

One important advantage which concrete has over stone masonry for foundations is in the rapidity and cheapness with which it can be placed in position. Masons must have room in which to work, and space for surplus material, mortar boards, etc. But few masons can be economically employed upon the foundations of even large structures. With concrete foundations, the excavation can be limited to the size of the foundation. The material may be stored at any convenient place, mixed there and conveyed to the foundation trench in wheelbarrows, by derrick and box, belt conveyor, inclined chutes, or by any of the many approved economical methods. After being dumped into place, as many men as the work requires may be used to properly dispose and ram the material into place.

These men may be unskilled laborers, but with a skilled foreman to direct, the work can be of the best quality.

It requires from one-eighth to one-third of the time to place a concrete foundation that it requires to construct one of stone. Within thirty-six hours after the completion of the concrete foundation, work upon the superstructure may proceed.

Those that know little about concrete may question its durability. For their benefit attention is called to the durability of concrete as illustrated in the historical portion of this paper. Portions of the Carthaginian aqueduct are intact after 2,000 years of weathering. The dome of the Pantheon still survives the ravages of 2,000 years. In 1892, while excavations were being made in London, workmen came upon a heavy mass of natural cement concrete laid over 800 years ago. Blasting was out of the question, owing to the proximity to other buildings. So workmen were employed to cut out the concrete with chisel and hammer. The concrete was so hard that it turned the best steel tools.

In 1872, J. V. Farwell erected a large store at the corner of Market and Franklin streets in Chicago, with foundations and interior walls of natural cement concrete. The building is still used for mercantile purposes with the concrete portion apparently as perfect as ever. Another of Farwell's buildings, erected in 1869, was in the path of the great Chicago fire of 1871. While the interior partitions of wood were burned out, the walls of concrete stood, so that within a very short time the building was repaired and was used by the Government for court, treasury and customs offices.

The United States Government in erecting the postoffice building in Chicago, in 1872, built it upon a cement foundation slab several feet thick extending under the entire building. In 1897 that building was torn down to make room for the new Federal building recently completed. The contractor was compelled to use steam drills and dynamite to remove the concrete, and because of its refractory nature was so delayed in finishing his work, that it entailed the payment by him of a penalty of \$100 per day for several weeks. With such a record for natural and "Roman" cements, greater results may be expected from the more perfect Portland cements.

HEAVY CONSTRUCTION.

From footing courses and foundation walls to abutments, retaining walls and heavy superstructure was but a step.

These are constructed both of massive concrete blocks and in monolithic form.

WALLS.

In the construction of the Consolidated Lake Superior Power Co.'s plant at Sault Ste. Marie, Mich., immense concrete blocks with mortised

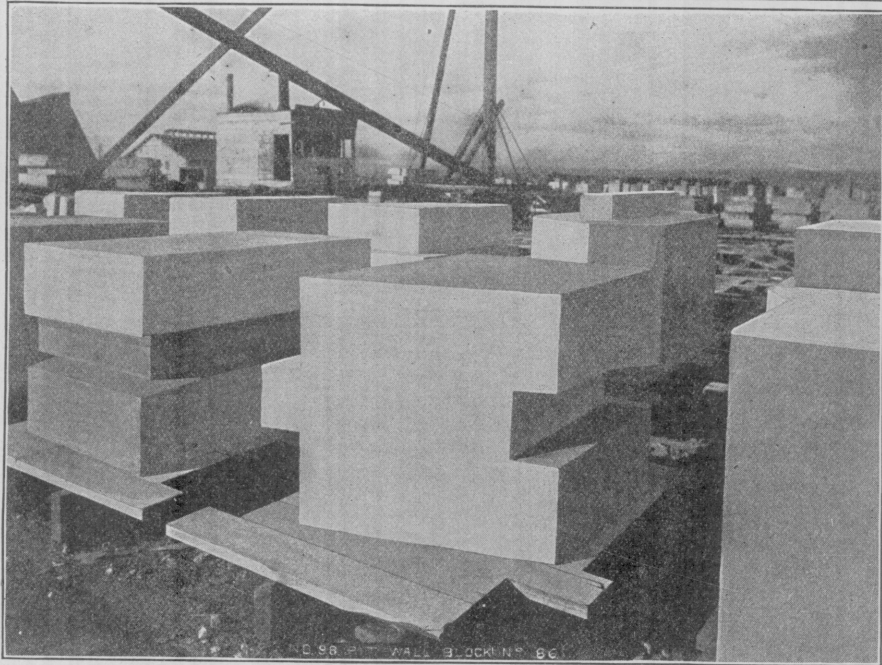


Fig. 12.—Concrete Blocks for the Power House of the Lake Superior Power Company.



Fig. 13.—View of the Pocket Walls of the Lake Superior Power Company, Showing Use of Concrete Blocks.

5—S. G.

joints were used in building the walls of the wheel pits. Figures 12 and 13 show the blocks and the wall respectively.

It is only during the last decade that railroad companies have been developing concrete construction along these lines to any extent. The Illinois Central, the New York Central and Hudson River railroad, and other large roads are now doing a great deal of concrete work.

ABUTMENTS.

In many cases when the old abutments and masonry walls are still in fair condition, but are not heavy enough for the increased weight of bridges and rolling stock, or because of added fills, the old masonry has been re-enforced by an additional casing of concrete, thus preserving the old masonry and adding a large percentage of strength to the structure. In other places the old masonry is removed entirely and concrete substituted.

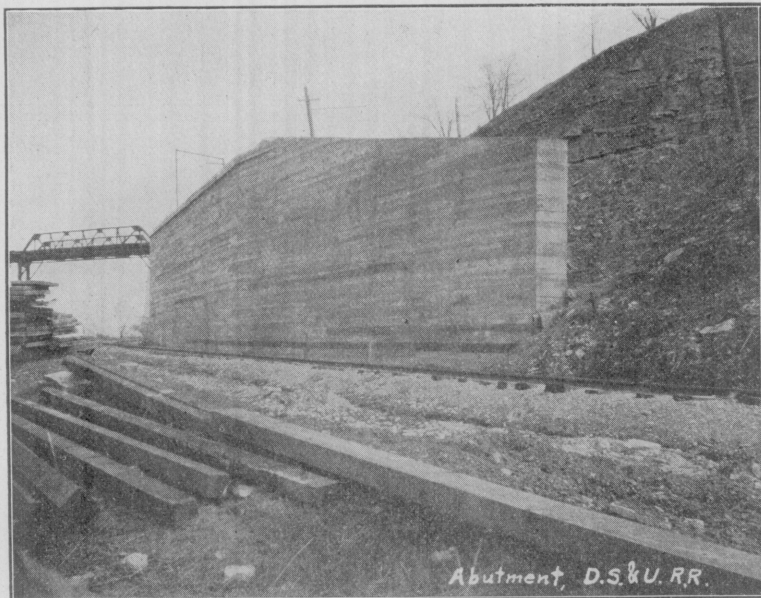


Fig. 14.—Concrete Abutment on the D., S. & U. R. R., Near Dayton, Ohio.

Some railroad companies have shown timidity in using concrete to entirely replace stone for piers and abutments of long span bridges; especially for the bridge seats, because of an uncertainty as to the durability of concrete under vibrating and impact strains. The New York Central and Hudson River railroad limits the use of concrete piers or abutments to bridges having spans less than 200 feet long.

The Dayton, Springfield and Urbana Electric Road has lately constructed two large abutments to carry their road over the tracks of the

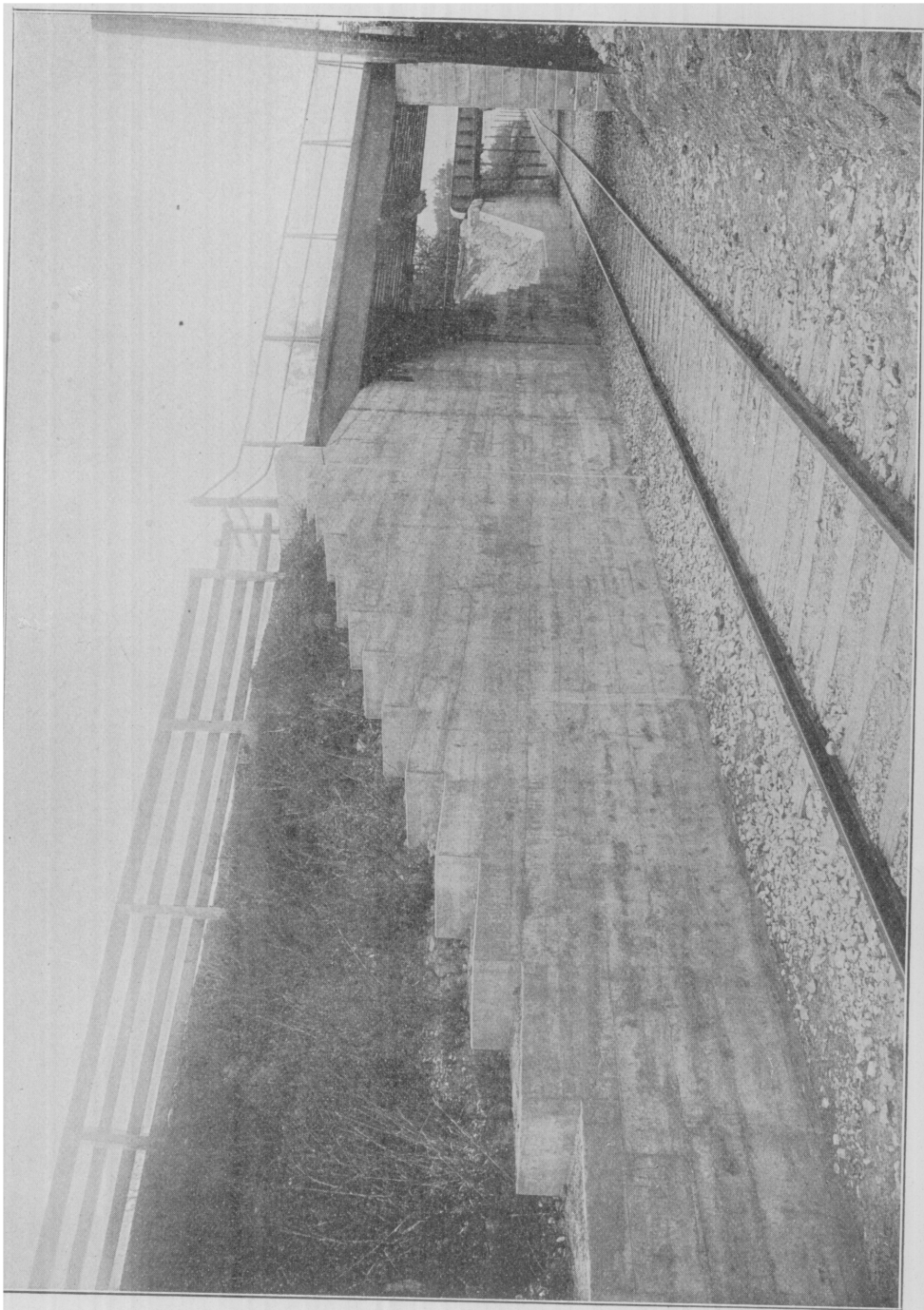


Fig. 15.—A Concrete Abutment on the T. & M. R. R., Near Toledo, Ohio.

C. S. & H. R. R. about three miles east of Dayton. These were constructed of a rich concrete of 1 cement, $2\frac{1}{2}$ sand and 5 broken stone. The largest of these abutments makes an angle of about 45 degrees with the center line of track and will support about 21 feet of earth behind the wall. It is about 120 feet long and contains 590 cubic yards of concrete. The concrete cost about \$5.75 per cubic yard, day labor being \$1.50 per day of ten hours, and cement \$2.10 per barrel. Figure 14 illustrates the abutment near Dayton, Ohio. Figure 15 shows an abutment upon the Toledo and Monroe Railway.

The Erie Railway is using concrete in nearly every place where stone was formerly used, in culverts, ashpits, foundations, etc. Furnace slag is used in place of gravel or stone. It only costs the railroad company for the hauling, as the furnace owners load it onto the cars for the sake of getting rid of it.

Concrete costs the railroad company about \$3.50 per cubic yard. The sand costs them about \$4.00 per car of 20 cubic yards, cement \$1.40 per barrel, and the slag only the cost of hauling.

CULVERTS.

The New York Central, the Illinois Central and many other large roads are using concrete almost exclusively for arch culverts. With the old stone culvert construction the roads were at a continual expense for repairs, pointing up, repairing wing walls, etc.; but with a well built concrete arch and wing walls, the culvert is in place for all time. A smooth impervious surface is presented to the elements so that weathering has practically no effect upon the structure. Besides being cheaper for maintenance, the concrete arch saves the expensive first cost of stone cutting in skew arches. Figures 16 and 17 neatly illustrate the decay of an old stone culvert and the smooth, water resisting surface of the concrete culvert replacing it. These pictures were taken of a culvert upon the Panhandle Railroad in the western part of Columbus, Ohio. Figure 19 shows a double culvert.

RETAINING WALLS.

Concrete retaining walls are being extensively used in the track elevation and depression carried on in such gigantic scale by the railroads entering Chicago.

The Lake Shore, and the Chicago and Rock Island railroads enter the fine large Van Buren Street station in Chicago over elevated tracks upon a fill 16 feet in depth held by concrete walls on either side. The wall along the east right of way from a point 140 feet south of Polk street has a section as shown in figure 18. The trench for the foundation is excavated about four or five feet deep, the aim being to get below frost line. The foundation is then laid with natural cement concrete of 1-2-4 proportions, to within about a foot of the surface; then continued to a



Fig. 16.—A Stone Culvert Near Columbus, Ohio, Showing Deterioration by Weather.

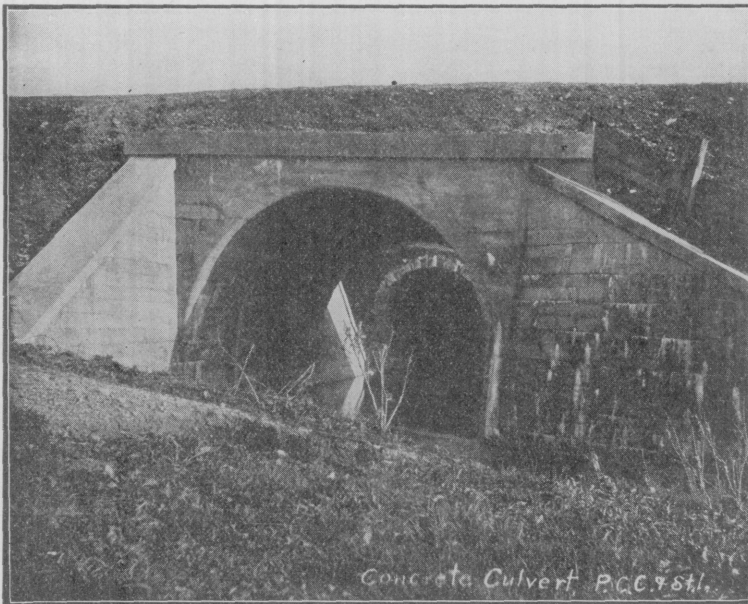


Fig. 17.—A Concrete Culvert Replacing That Shown in Fig. 16.

finish with Portland cement concrete of the proportions 1-3-6. The excavation cost 50 cents per cubic yard, natural cement concrete \$4.00 per cubic yard and Portland cement concrete \$6.25 per cubic yard, making the cost of the maximum section as shown in the accompanying figure to be \$23.65 per lineal foot of wall.

The wall upon the west side of the right of way is designed with a base width of four-tenths its height, consequently is considerably cheaper; the cost of such a wall being \$20.53 against the cost of the first or a saving of 15 per cent. on the basis of the lighter wall, the latter being perfectly safe practice.

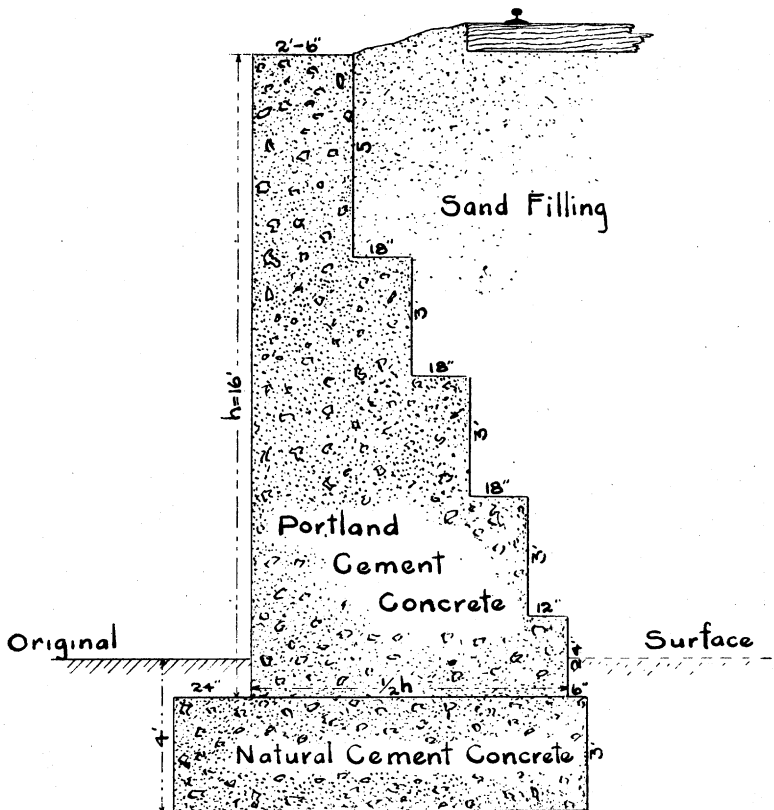


Fig. 18.—Section of Retaining Wall C. R. I. and P. R. R. Showing Maximum Section.

The contract specifies that the cement shall be of first class quality, acceptable to the railway company. The sand shall be what is known as torpedo sand. The stone shall be good crushed limestone. The wall was

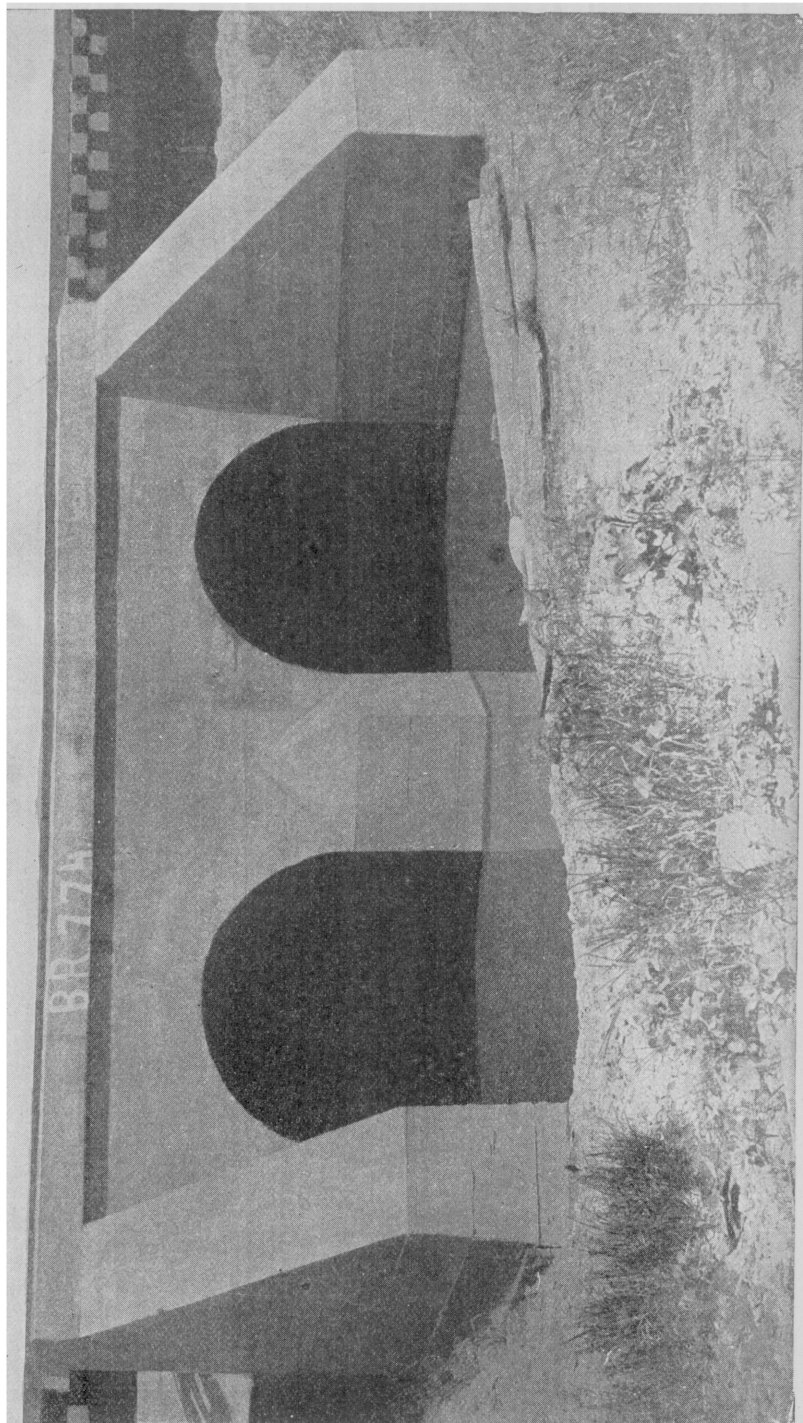


Fig. 19—Double Six-Foot Culverts, Rankin, Ill.

put up in 48 foot sections, thus leaving a vertical joint every 48 feet for expansion. In the wall on the eastern right of way, the forms were held together by iron rods running through gas pipes; these rods were afterwards removed and the holes cemented up. On the western right of way the forms were held together by wires which were cut off after the forms were removed. This method of placing forms is illustrated in Figure 20.

LEEVE WALLS.

Similar to the retaining walls are the walls built to withstand the pressure of high water along river banks. While levee walls are usually

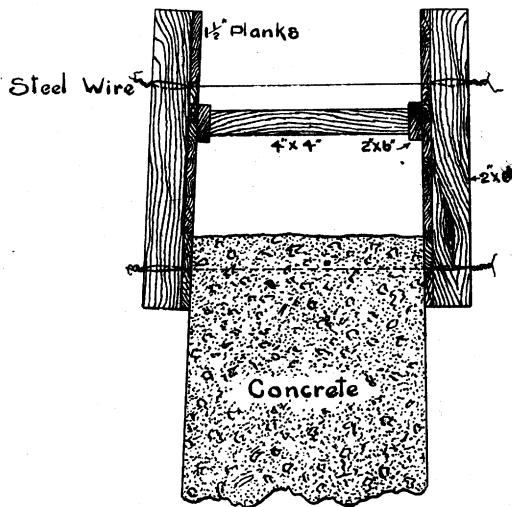
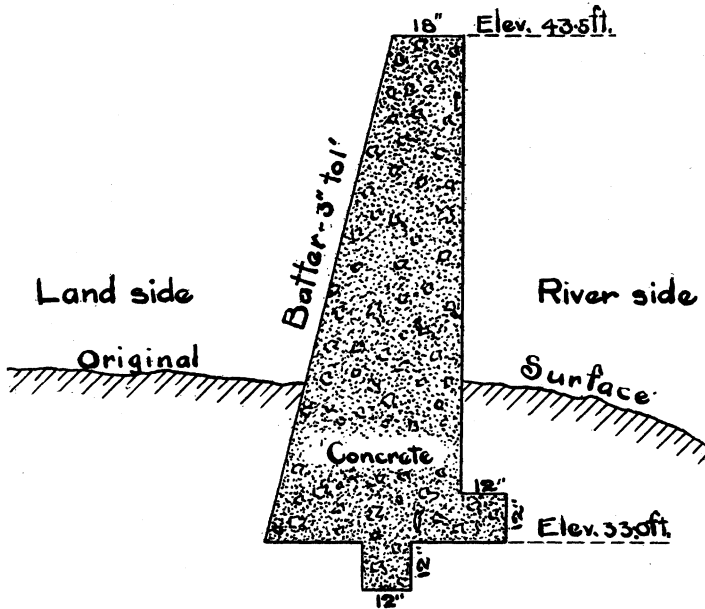


Fig. 20.—Section of Concrete Wall-Form, Showing Method of Holding and Bracing Forms, C. R. I. and P. R. R.

built of earth, the city of Columbus has 245 feet or more constructed of concrete. Property and space in the heart of cities often becomes too valuable to use ordinary methods of construction in making the necessary improvements, and recourse is had to what at other times would be more expensive methods. In this case space was too valuable for earth embankment and a concrete wall was constructed by the city with day labor. Figure 21 shows a section of this work.

The wall was 18 inches thick at the top and 50 inches at the bottom with a maximum height of 11½ feet. The heart of the wall was constructed of concrete with the following proportions, 1 part Portland cement, 2½ parts sand and 5 parts crushed gravel. The face of the wall

for a thickness of two inches was of mortar, 1 cement to 2 sand. A careful force and expense account was kept of the work which was done in



Section of Concrete Levee Columbus, Ohio.

Fig. 21.

two pieces, one of 185 feet and the other 60 feet in length. The cost of each is as follows:

TABLE NO. 18.

Cost of Levee wall at Columbus, O.

Items used in each cubic yard of Concrete.	Cost per cubic yard upon	
	60 ft. length.	185 ft. length.
0.94 barrel Portland cement at \$2.15.....	\$2.021	\$2.021
1.10 cubic yards of crushed gravel at \$0.75....	0.825	0.825
0.55 cubic yard of sand at \$1.25.....	0.687	0.687
Labor mixing—placing and ramming at \$0.15	1.160	1.324
Extra cost per yard, facing with 1 to 3 mortar..	0.264	0.221
Cost of labor, erecting forms.....	0.265	0.232
Cost of materials in forms.....	0.379	0.391
Deterioration of tools and equipment.....	0.042	0.055
Total cost per cubic yard.....	\$5.643	\$5.756

FORTIFICATIONS.

Concrete is extensively used by the U. S. Government in the construction of gun foundations and emplacements in magazine vaults, bomb

proofs, and in all masonry construction about the sea coast defences. The great disappearing guns are set in immense concrete masonry chambers with concrete foundations for the machinery.

MONOLITHIC CONCRETE HOUSES.

The oldest concrete house built in the United States is of monolithic concrete. It was built on Staten Island, N. Y., in 1837, of natural cement concrete. Although badly weather worn and dilapidated, this house still stands and was inhabited by one or two families when the writer visited it in 1902. It must be remembered that this house was built of the imperfect natural cement made in those early years and the aggregate used was not carefully selected, but portions were composed of brickbats, irregular and rather large sized broken stone, etc., therefore the dilapidation shown. In front of the house at the gateway, lie two cast concrete lions, one badly cracked and crumbling, the other yet in fair condition after many decades of weathering. Figure 22 shows a front view of the house with the figure of one of the lions.

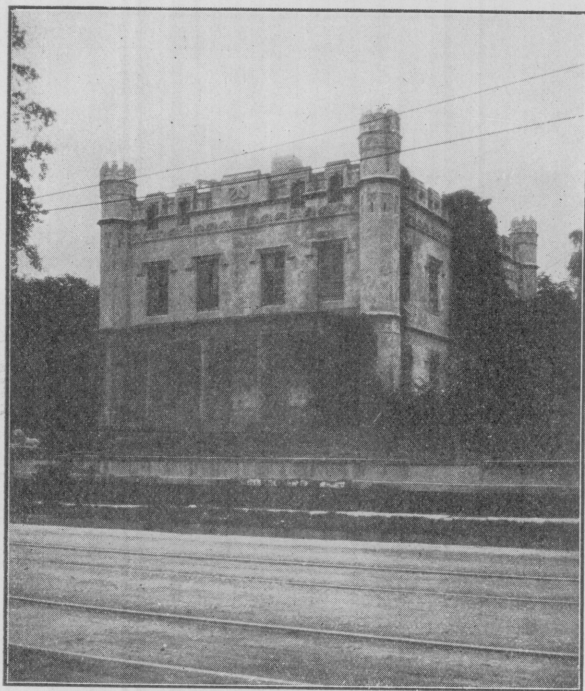


Fig. 22.—The Oldest Concrete House in the United States. Built on Staten Island in 1837.

CONCRETE BLOCK HOUSES.

Of the later forms of concrete house construction, none is neater, simpler, nor more economical than that constructed of the various forms

of blocks now manufactured of which the Palmer hollow block is a good illustration. The simplicity with which these blocks are molded and the latitude of design obtained upon the one simple machine leaves little more to be desired. The machine covers but small space, is fairly light, is readily moved from place to place and is easily prepared for molding different shaped or sized blocks. Four men, two mixers and two tampers, will make from 100 to 125 blocks a day. The usual size for the blocks are 32 inches by 9 inches by 10 inches. The sides and ends of the machine swing out and down upon hinges. The hollow places in each stone are formed by metal wedges or cones raised into place, through the base plate by means of a cog and ratchet attachment. The side plates can be readily changed so as to substitute smooth, quarry faced, or ornamental facing for the stone as desired.

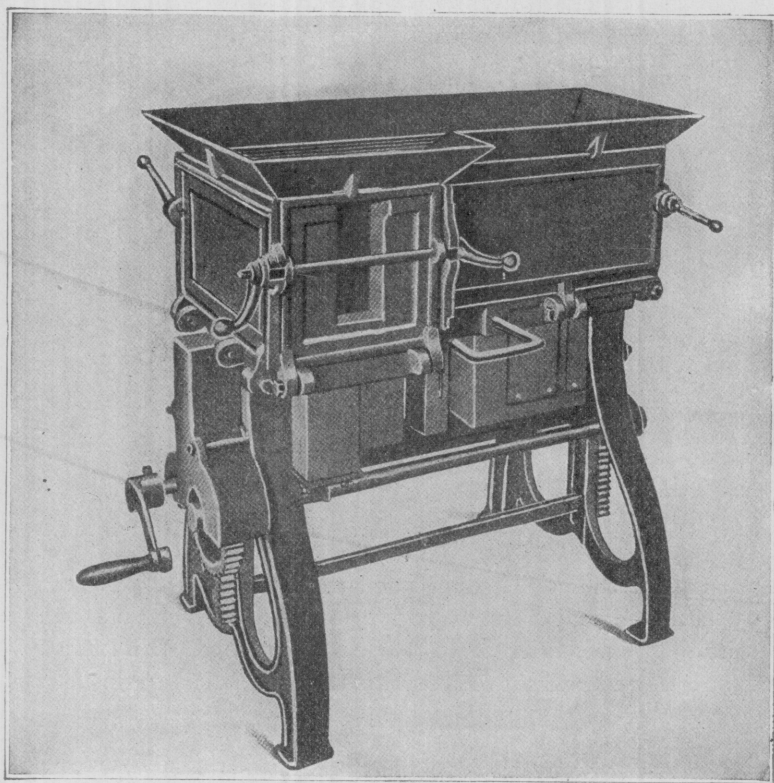


Fig. 23.—Palmer Concrete Hollow Block Machine.

The concrete is tamped into the machine, upon thin iron base plates, so that as soon as the block, which is made of rather dry concrete, is finished, the sides are let down, the hollow centers lowered and the block is lifted out on this base plate and allowed to remain upon it until firmly

set. Narrow iron tampers are used to tamp the concrete into the mold. The top of the block is troweled smooth before removing it from the form. After three or four hours, or as soon as the concrete has sufficiently set, the blocks are wet down, water being applied twice a day for three or four days. The blocks are allowed to set ten days or more before being laid in the wall.

Four men can lay about 60 blocks a day, equal to about 2,200 to 2,500 bricks, or $112\frac{1}{2}$ square feet of wall surface.

The concrete is made of 1 part Portland cement and 5 parts coarse sand. Tests made upon such blocks at four months of age have shown 80,000 pounds compressive strength. Figure 23 shows the Palmer machine which is about two feet wide, three feet long and three and one-half feet high. Figure 24 shows the various shaped blocks and the purpose for which each is made. Figure 25 shows a residence under construction near Indianapolis, Ind. Figure 26 is from a picture of a residence in Springfield, Illinois.

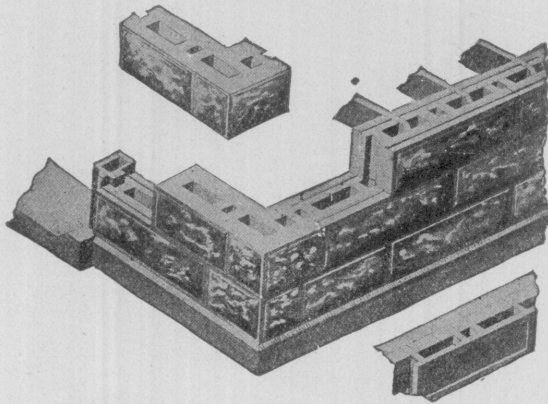


Fig. 24.—Palmer Concrete Hollow Blocks.

Mr. Palmer claims that each standard block takes the place of forty bricks; that each block can be made for twenty-two cents and hence economically replaces brick at \$5.50 per one thousand. And further, that these blocks can be laid much more rapidly than brick, saving something also in labor.

An Estimate of the Cost of Making the Palmer Block.—Assume cement to cost \$2.00 per barrel, sand, \$1.60 per cubic yard, common labor, \$1.50 per day, with the foreman's wages \$2.25 per day, the estimate to be based upon the work of one machine using four men. The regular block contains $1\frac{1}{8}$ cubic feet of material and weighs about 165 to 170 pounds. Assuming the weight of cement at 80 pounds and that of sand at 100 pounds and assuming that four men can make 100 blocks per day of eight

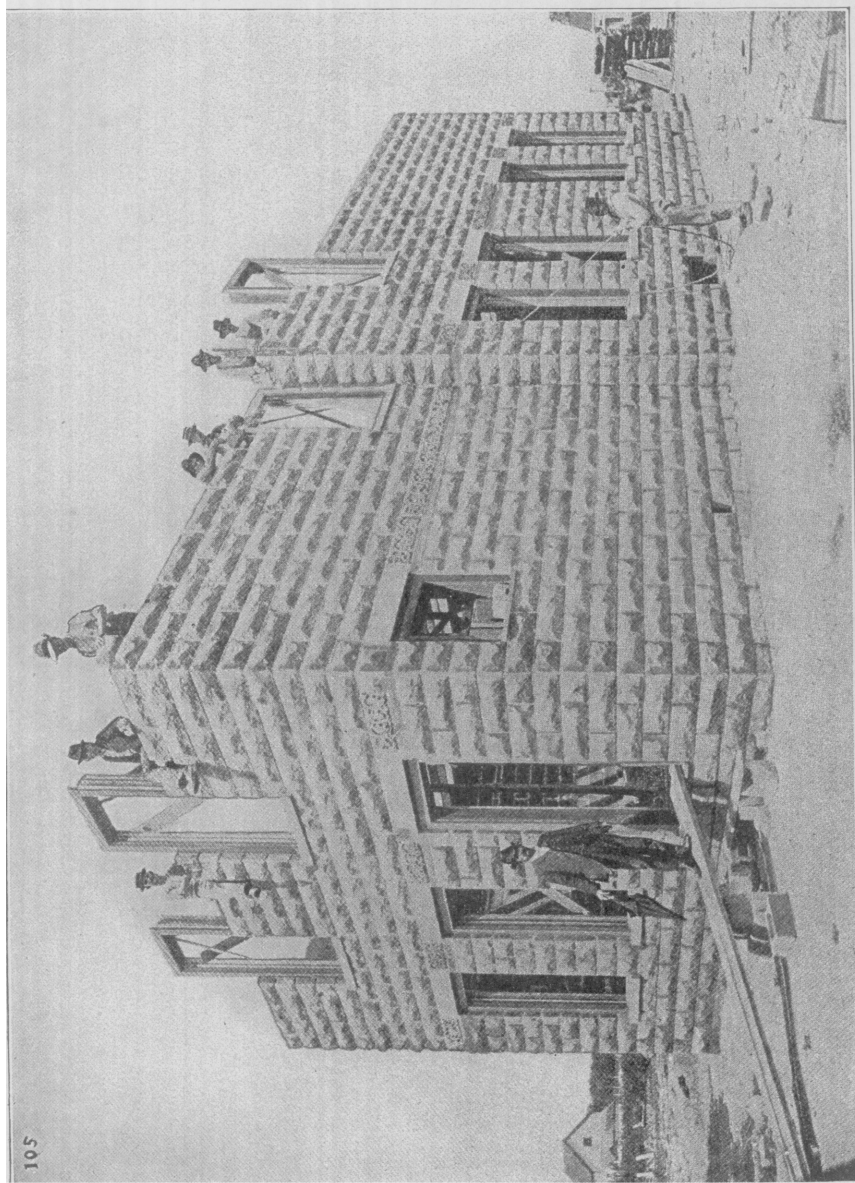


Fig. 25.—A Residence in Indianapolis Being Constructed of Concrete Blocks.

hours, the following will be an approximate estimate of the cost of one hundred blocks:

Four men, 3 at \$1.50 and 1 at \$2.25.....	\$6.75
Cement, 5.8 bbl. at \$2.00.....	11.60
Sand, 5.8 cu.yds at \$1.60.....	8.00
Cost of one machine plan, \$750, int. at 6%.....	0.15
Depreciation, 20%	0.05
	\$27.00

or 27 cents per block equal to brick at \$6.75 per 1,000. Using the table in Prof. I. O. Baker's book on Masonry Construction, page 86, the cost would be 23½ cents per block equal to brick at \$5.70 per 1,000.

Mr. F. E. Kidder,* author of "Architects' and Builders' Pocket-Book," made a test of the cost of concrete blocks with a machine of the American Hydraulic Stone Company's make during March, 1903. The test was made on facing block for a 10 inch wall; two of these blocks would lay 9 inches by 24 inches in the wall. The main portion of the block was composed of 1 part cement to 6 parts sand and gravel, with a face of 1 cement to 2 sand.

Cost Per Square Yard of Wall.

Labor 1 man, 1 hour 15 min., at \$2.00 per day of 10 hrs...	\$.25
Cement, 0.78 sack at \$0.62½ per sack.....	.48¾
4 cu. ft. of sand and gravel at 75c. pepr 1¼ cu. yds.....	.09
Extra cost of facing material	.01¼
Cost of twelve blocks.....	\$.84
Cost of mortar and laying 1 sq. yd.....	.48
Cost of hauling blocks to place of construction per yd.....	.10
Total cost of 1 sq. yd. of 10-inch wall.....	\$1.42

He estimated brick layed at \$12.50 per 1,000, and adding \$30.00 per 1,000 for pressed brick facing, making no allowance for cut stone trimmings, the cost for a 9-inch brick wall would be \$3.57 per square yard, and for a 13-inch wall, \$4.41 per square yard.

BRIDGES.

In bridge building as in other lines of construction concrete has taken its place as a permanent structural material. In small country highway bridges, the highway commissioner frequently considers himself not only able to decide upon the character of bridge to be erected, but also competent to design it. Wooden or metal bridges are erected and from the day they are finished not a thought is given to their maintenance. They are allowed to weather, rot and rust away until some accident occurs or

*Eng. News, Sept. 17, 1903.

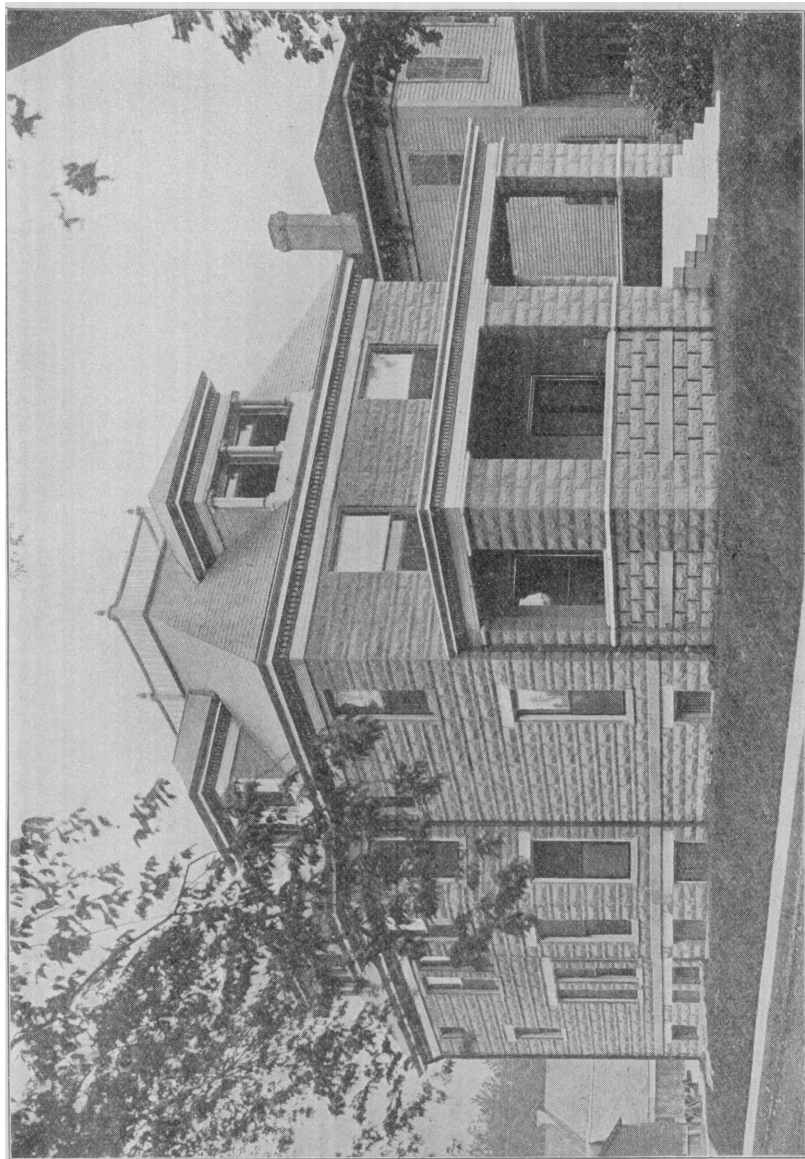


Fig. 26.—Residence Built of Concrete Blocks, Springfield, Ill.

warning of such accident forces the attention of the authorities to the condition of the structure. Neither is the commissioner altogether to blame—for when one official more careful than others reports the necessity for the proper painting and maintenance of bridges, he will probably meet the serious objection from the tax payer—that “there are enough expenses now, without trying to make an out-of-the-way bridge look pretty.” If anyone doubts the expensiveness of this careless method of bridge maintenance, he has only to examine some of the highway bridges crossing the Olentangy and Scioto rivers in Franklin county, Ohio, to note how little of real value is left in bridges after a few years of neglect.

Concrete bridges and culverts, however, have no corrosion. If they are properly constructed they neither weather nor rot. The commissioner may be as careless as he chooses, the tax payer need not be taxed again for that particular bridge, it is there for the tax payer’s lifetime, and probably that of his son’s also.

Concrete bridges are constructed both of plain concrete and of steel concrete, mainly of the latter material. At this place only the plain concrete bridge will be considered, leaving the descriptions of steel concrete bridges to be given with other structures under that division of the subject.

Probably the first all-concrete bridge of any size constructed in this country was built at Belleville, Illinois, in 1895. It was built over Richland creek where it crosses Main street, the main traveled road leading directly to St. Louis, Mo. It has a span of 40 feet with a rise of 7 feet and is 52 feet wide over all. The abutments, spandrels, and haunches were constructed of Louisville cement concrete in the proportions of 1 cement, 3 sand and 5 crushed stone. The arch was built of Dyckerhoff Portland cement concrete of the same proportions. Exposed finished surfaces were of mortar composed of 1 cement to 2½ parts of crushed granite. The arch is 24 inches thick at the crown and 30 inches thick at the haunches. It cost \$10,500; the bids upon a brick structure in this place ranged from \$11,259 to \$12,830.

After eight years’ service, the city engineer of Belleville, Mr. Louis Graner, writes: “The bridge is in perfect condition and the city has had no expenditure in any way since its construction. It shows no cracks and the weather has had no effect on it.”

There are a great many concrete bridges throughout the United States, but the majority of them are of steel concrete construction and some of them will be described under that head.

TOWER SUBSTRUCTURES.

Massive concrete is also used in foundations, pedestals and substructures of towers, and monuments. The statue of Liberty on Bedloe’s Island is placed upon a massive stone faced concrete pedestal rising for

90 or 100 feet above the top of an all concrete base which is itself 50 or 60 feet in height above the surface of the island. The interior surface of all the concrete is as good as the day it was built. In places where it has been cut into, the material appears more refractory than ordinary building stones. The surface of the base was plastered with cement mortar after the construction forms were removed and this mortar surface shows an immense number of hair-cracks which give the base an unseemingly appearance, but which do not injure the strength of the foundation. These cracks do not appear on surfaces not exposed to rapid drying. The base is built of a natural cement concrete having the following proportions, 2 parts Rosendale cement, 2 parts sand, 3 parts small broken stone and 4 parts of 2 inch stone. Above ground the proportions are 1 Portland cement, 1 Rosendale cement, 5 sand and 6 stone. The total height of the statue above water level is 324 feet. Figure 27 shows the lower base of the statue of Liberty. Close examination will disclose the hair-cracks so common to plastered surfaces. Figure 28 shows the Statue of Liberty.

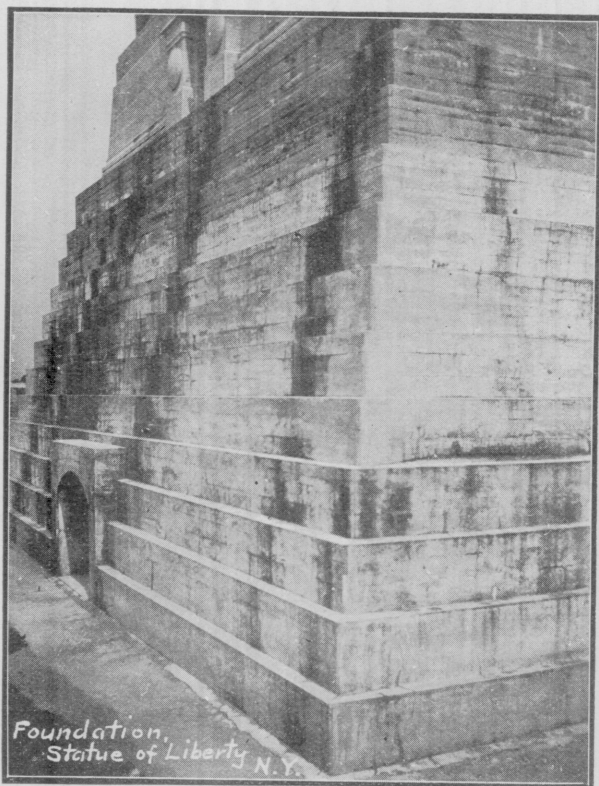


Fig. 27.—Concrete Foundation Statue of Liberty, New York Harbor.

The Washington monument is also an instance of the use of concrete for heavy foundations. The monument is of marble and granite 555 feet high and 50 feet square at the base. The corner stone was laid on July 4, 1848. The construction was carried on in a desultory manner so that the monument was not completed until 1884. In 1877, when the tower was about 175 feet high, it was decided that the original foundations were not of sufficient extent and strength to safely support the finished tower. An additional concrete sub-foundation 13½ feet deep and covering 21,000 square feet of surface was skillfully constructed beneath the original foundation in sector shaped pieces. The concrete was composed of 1 cement, 2 sand, 3 gravel and 4 broken stone. The result seems to be perfectly satisfactory.



Fig. 28.—Statue of Liberty, New York Harbor, Showing Concrete Pedestal in Full.

SEA WALLS.

The concrete sea wall built by the United States government during its occupation of Cuba, along the sea front of the fort of La Punta in Havana, illustrates the use of concrete for this purpose. A wall was first planned for this place by a Spanish officer in 1875, but was not built. When

the Americans occupied Havana, this shore was used for a refuse dump and was in a seriously unsanitary condition. Under the changed conditions, it was necessary to construct a different improvement than that planned by the Spanish officer. The work was done under the direction of Major Wm. M. Black, of the Engineering Corps of the U. S. A. The wall was set back 30 feet from ordinary high water mark and a paved toe extends down the slope about 26 feet, having stones set in the paving and extending above the surface of the same in order to retard the wave effect. Three hundred and sixty-seven feet of wall was built during the last four months of 1900. The toe was built first to act as a protection during the erection of the wall proper, which was afterwards built in sections from 33 to 50 feet long with vertical dovetail joints, to bond the sections together. Near the fort, a broad flight of steps was constructed to give access to the beach and to break the effect in appearance between the modern concrete wall and the ancient masonry of the fort. The total cost of the improvement was \$9,567.00. The wall was constructed of a 1-2½-5 concrete, faced 2 inches deep with a 1 to 2 mortar. The facing was placed in the molds and rammed at the same time with the body of the concrete.

The toe pavement was constructed of a 1-3-6 concrete top-dressed with 2 inches of 1 to 2 mortar with large stones projecting above the surface as shown in the illustration, figure 29.

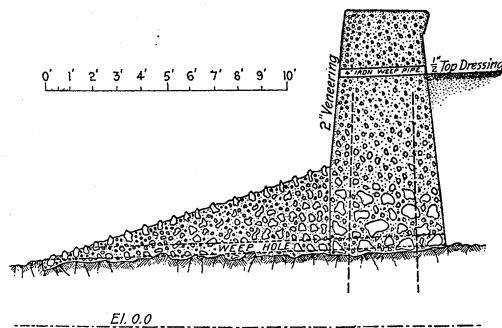


Fig. 29.—Section Showing Sea-Wall Building at Havana, Cuba.

Galveston Sea Wall.*—In September, 1900, a storm of great severity swept over the island upon which the city of Galveston, Texas, is situated, carrying the waters of the gulf over the island to a depth varying from 10 to 16 feet. The city suffered a great loss of life and property by this storm. Soon afterward a commission of engineers was appointed by the city to devise adequate means of protection against repetitions of such storms. This commission found that in 38 years 82 hurricanes originated in the West Indies of which 38 came into the gulf and 11 reached the

**Eng. News*, April 24, 1902 also, *Eng. News*, January 15, 1903.

Texas coast, or one storm for each three and one-half years. If Galveston was to prosper, ample protection must be afforded against these oft recurring dangerous storms.

The commission proposed and the city is now building a great sea wall three and one-half miles long of solid concrete, the monolithic character of concrete suggesting a safer wall than block masonry, besides being very much cheaper in first cost.

This wall is being built upon a pile foundation, the heads of the piles extending about 2 feet above mean low water. The wall is 16 feet wide at the base, 16 feet high, and 5 feet wide at the top, with a curved water face. The base of the wall is one foot above mean low tide, resting on and enclosing the top of the piles. Extending the toe of the wall there will be 27 feet of stone rip-rap 3 feet deep, protecting the wall from under wash by wave action. Behind the wall the land will be filled to the height of the wall for a width of 95 feet; the 35 feet next the wall being paved for road and walk purposes, the remainder being well sodded.

It is estimated that the complete wall will contain 127,000 cubic yards of concrete and that the entire protection will cost \$3,500,000.

Figure 30 gives a section of the wall, and improvement as it is being built.

Lincoln Park Shore Wall.—The concrete shore wall along the lake in Lincoln Park, Chicago, is another example of first class concrete work. Like the Havana wall, the Lincoln Park wall is protected from the direct assault of the waves by an intermediate pavement, which in this case is of granite blocks firmly set between a strong curbing at the water's edge and the wall. On the inner or land face of the wall is a concrete gutter or bicycle path. The illustration in figure 31 shows the general appearance of the improvement which has been in for ten or fifteen years.

At Jackson Park, Chicago, similar improvements with a broad concrete walk were constructed previous to the World's Fair.

BREAKWATERS.

Concrete breakwaters have been constructed for many years, and by nearly every country having a sea coast. Concrete superstructures upon random stone substructures have been built in India, Turkey, Russia, Austria, Holland, England, and the United States. They range from 24 to 50 feet high and from 12 to 38 feet wide on top.

At Newhaven, on the south coast of England, a plastic concrete breakwater 1,500 feet long and 30 feet wide, 10 feet above high water, was constructed in 1880-85. It was 50 feet wide at the bottom some 15 feet below low water, at spring tide. The foundation up to 2 feet above low water was laid in large jute bags containing 100 tons of concrete. They were dropped into place from the bottom of a patent steam hopper barge. When in

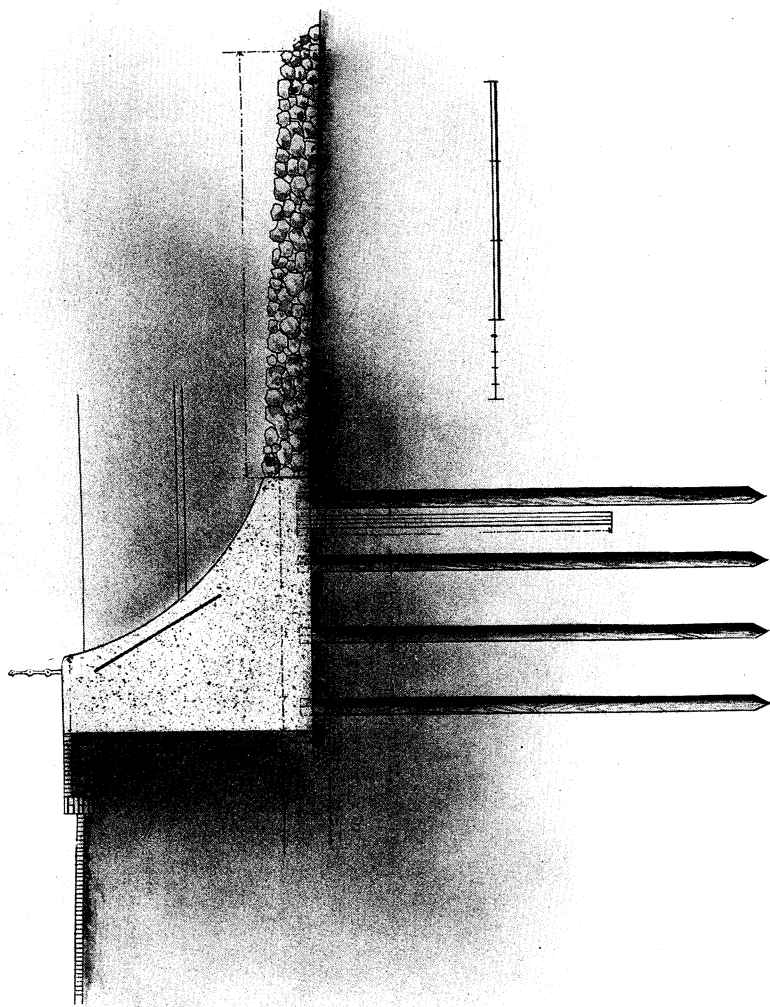


Fig. 30.—Sea-Wall in Process of Construction at Galveston, Texas.

place and flattened out the bags were about $2\frac{1}{2}$ feet thick. The forms for the superstructure were of timber trussed with $1\frac{1}{4}$ inch iron rods, the sheeting being of 3 inch plank, with planed edges and surface. The concrete was composed of 1 cement to 7 sand and gravel, except in quiet water and unexposed places where 9 parts of sand and gravel were used. The average cost of the concrete in place was \$5.50 per cubic yard. This work has withstood the wave action excellently and is not affected by salt water.



Fig. 31.—Concrete Shore-Wall, Lincoln Park, Chicago, Ill.

The timber breakwater constructed at Marquette, Mich., in 1870, became inadequate for the needs about 1888, and efforts were made to have the government extend it. These efforts finally succeeded in 1895, and the government proceeded to improve the harbor. The old breakwater was in bad condition above low water and it was decided to replace the timber top with a permanent one of concrete.

The original structure was cut down to one foot below low water and the concrete superstructure with dimensions as shown in figure 32 was added. Within this solid concrete mass on the harbor side a gallery 2.83 feet wide and 6.25 feet high was built to give a passageway during heavy storms to the lighthouse at the end of the breakwater. The superstructure was made in 10 foot sections, alternate sections being constructed and allowed to set, then the intermediate blocks built between. The proportions of Portland concrete used in the base beneath water level was 1 part cement, $2\frac{1}{2}$ parts sand, and 5 parts stone, and cost \$6.35 per cubic

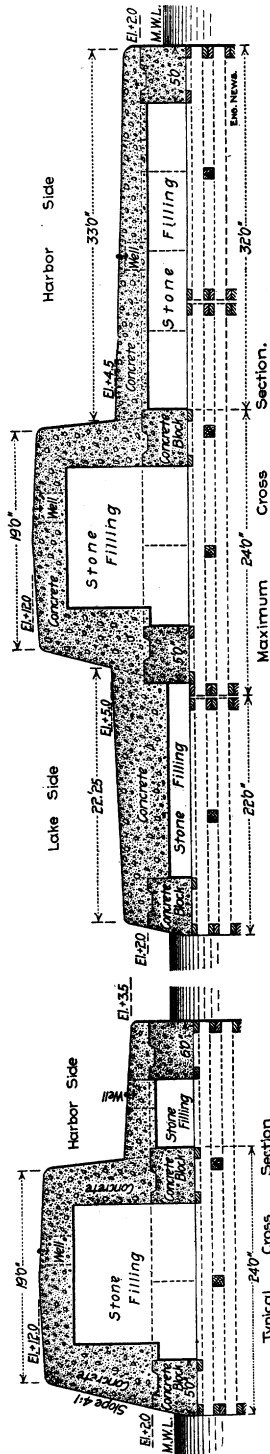


Fig. 33.—Section of Breakwater, Buffalo, N. Y.

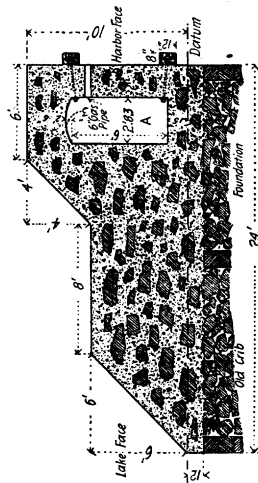


Fig. 32.—Cross Section of Breakwater, Marquette, Michigan, Showing Passageway to the Lighthouse at the End.

yard in place. Milwaukee natural cement concrete was used for about 27 per cent. of the heart of the mass above low-water; this cost \$3.64 per cubic yard, and reduced the cost of the total mass of concrete to \$4.72 per cubic yard, in place.

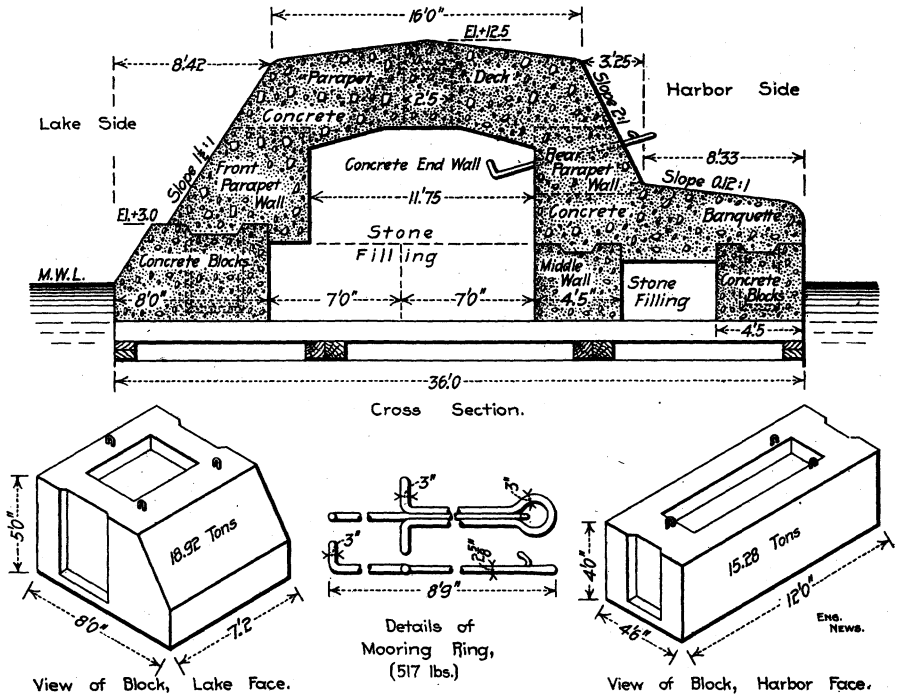


Fig. 34—Section of Buffalo Breakwater Showing Method of Construction.

The section shown will illustrate the manner of construction and the method of reducing the shock of wave action.

The Buffalo breakwaters, but lately completed, constitute one of the largest pieces of such work undertaken by the Government. The Buffalo breakwaters are known as the Stony Point, South Harbor, Old and North breakwaters, comprising 19,872 feet, or $3\frac{3}{4}$ miles, of harbor protection, enclosing about 1,000 acres of harbor. Some portions are rock-filled timber cribbing, other portions are loose rock rubble work, but large portions are now capped with concrete either in large blocks or monolithic. In portions of the work, concrete blocks 7.2 by 5 by 8 feet in dimensions and weighing 18.92 tons were carefully set in place and interlocked by dovetail or joggle joints. On top of these, monolithic concrete caps were constructed. Sections are given in figures 33 and 34 showing the different forms and methods of construction used. Figures 35 and 36 show the work in different stages of construction.

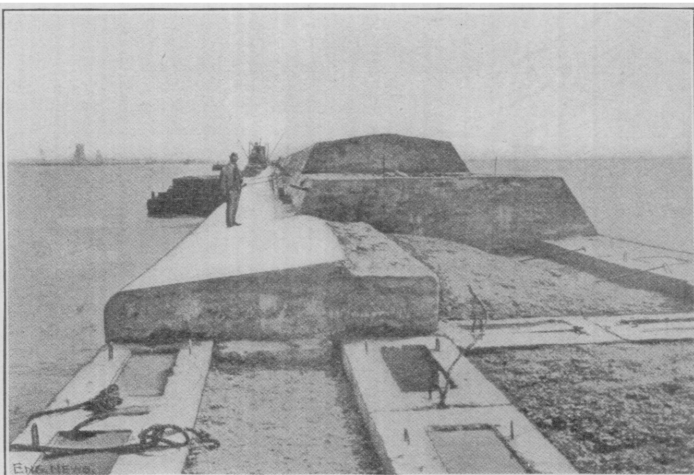


Fig. 35.—View of Buffalo Breakwater in Process of Construction.



Fig. 36.—Another View of the Buffalo Breakwater in Process of Construction.

The following table gives the cost for various portions of this work:

TABLE No. 19.
Cost of Breakwaters.

	Superstructure per lineal foot.	Concrete blocks per cubic yard.	Mass concrete per cubic yard.
Old U. S. Breakwater, solid concrete superstructure, 1889	\$110.19	.....	\$9.19
Old U. S. Breakwater, solid concrete superstructure, 1891	108.32	.....	8.21
Old U. S. Breakwater, con- crete shell.....	72.26	\$ 6.64	6.64
North Breakwater, 36 foot sec- tion.....	56.84	7.10	5.65
North Breakwater, 24 foot sec- tion.....	46.02	7.10	5.65
South Harbor, concrete shell superstructure.....	108.49	10.00	9.40

Concrete wharves, piers and river jetties have also been constructed. The Eads' jetties at the mouth of the Mississippi River are for a portion of their length of concrete, an illustration being given in figure 37.

SEWERS.

During the last few years concrete has been used in increasing quantities for sewer construction. The first use of concrete for that purpose, in this country, appears to have been in 1891. The Waring Sewer Pipe Co., of Providence, R. I., patented during that year a method of manufacturing sewer pipe in sectional pieces. They cast it in smooth iron molds, the invert and arch, separately. The invert pieces were rabbeted or grooved at the ends so that when two pieces were laid end to end the groove could be filled with mortar.

The arch pieces had beveled shoulders which fitted snugly upon the top edges of the invert; the arch joint being plastered over with mortar from the outside. Lateral connections were made through specially molded junctions. The 4-foot main sewer, in Middlesborough, Ky., was constructed by this company, the invert being built in place. The cost, according to the construction company, was 25 per cent cheaper than brick sewers.

In the same year A. C. Chenowith, C. E., invented a seamless concrete duct which was applicable either to sewer or electric duct service. The first piece constructed was for electric ducts in Yonkers, N. Y. A thin iron ribbon was wound spirally over a collapsable wooden mandrel or core, a bed of plastic concrete was laid in the trench and the core laid upon this and then covered with another layer of concrete. The wedges were then taken out and the mandrel removed leaving the iron ribbon as a shell to support the concrete until set, when the ribbon could be readily removed.

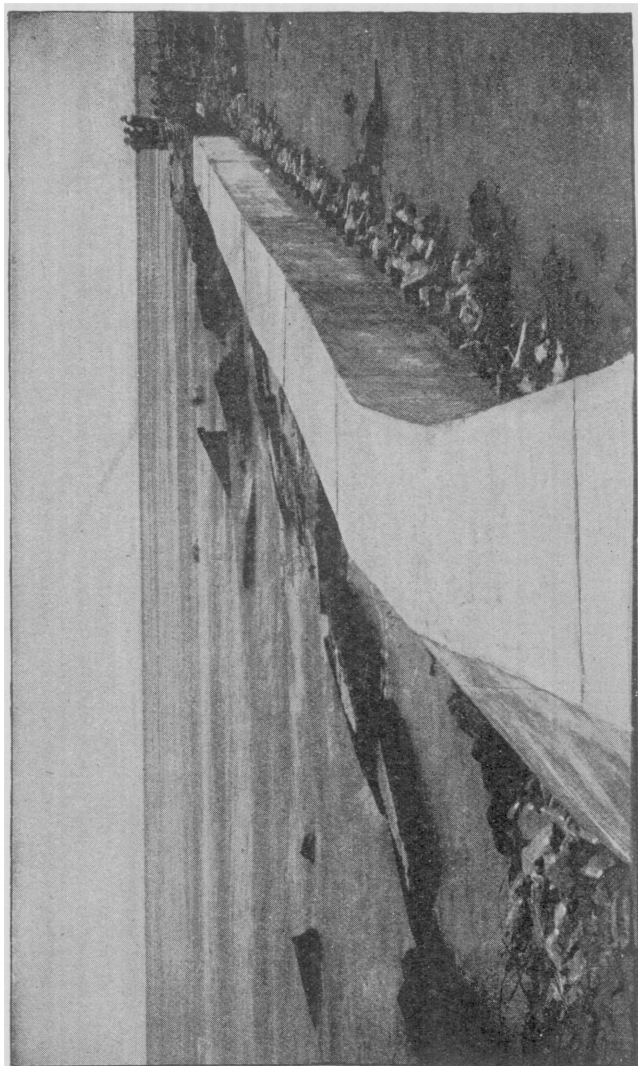


Fig. 37.—The Use of Concrete at the Jetties, Mouth of Mississippi River.

In 1894 over a mile of ten-inch and twenty-four inch pipe of this make was laid at Scarborough-on-Hudson, of a concrete composed of 1 cement, 2 sand, 5 stone at a cost of 30 cents per foot for the 10 inch and 95 cents per foot for the 24 inch sewer.

Edward Mahun, C. E., constructed a large egg-shaped sewer, 2 feet by 3 feet and 2 feet 10 inches by 4 feet 3 inches in dimensions, of monolithic concrete, for the city of Victoria, B. C., in 1891. This shows that several engineers began the work at about the same time.

A large concrete storm sewer was constructed for Maelbeek creek, Brussels, Belgium, in 1895. This sewer had a circular form with a diameter of about 15 feet in one part, and a section in another part of 29 feet 7 inches wide by 9 feet high. The remarkable feature of this large concrete structure was the leanness of the concrete. The foundation was of 1 part cement, 6 parts sand and 12 parts gravel, while the sides and arch were of 1 part cement, 4 parts sand and 8 parts gravel with a 1 inch face of 1 to 1 mortar.

Reading, Pa.—In 1896 the city of Reading, Pa., constructed a large amount of concrete sewers ranging in size from an oval sewer 4 feet 8 inches wide by 7 feet high to a circular sewer 14 feet in diameter. Some \$250,000 to \$300,000 was expended in combined sewers for the city. These were plain concrete sewers—no metal being used to reinforce the concrete. The concrete was proportioned as follows: 1 part cement, 3 parts sand and 6 parts broken stone or gravel. The work was plastered upon the inside with cement mortar after the forms were removed. This plaster coat has peeled off in a very few places of limited extent, otherwise the appearance of the sewer is as good as when it came from the forms.

The writer visited Reading in the summer of 1902 and examined the sewers, but could see no appreciable evidence of wear or disintegration except as already stated. The engineer said there were velocities ranging up to 19 feet per second or greater, in some places in these sewers. At the outlet an abrupt 90 degree bend in the sewer shows no evidence of wear.

At the time the contract was let there were 15 bidders upon the work. Alternate plans were drawn, one for brick, the other for concrete—the 14 foot sewer with 4 rings of brick or 18 inches concrete, the 10 foot sewer with 4 rings of brick or 15 inches of concrete, the 6 foot sewer with 3 rings of brick or 10 inches of concrete. The average of the bids upon the concrete was 85 per cent. of the bids for building the same sewers with brick. Comparing each bidder's prices upon concrete with his prices upon brick sewers, the bids upon concrete ranged from 67 per cent. to 103.6 per cent. of the prices bid for brick sewers.

Columbus Sewers.—A brief description of the concrete sewer work now under construction in Columbus, Ohio, should also be given.

Bids were accepted April 14, 1903, upon three different plans of sewer construction for the Central Relief and the Beck Street sewers. These sewers range from 51 inches to 10 feet 6 inches in diameter.

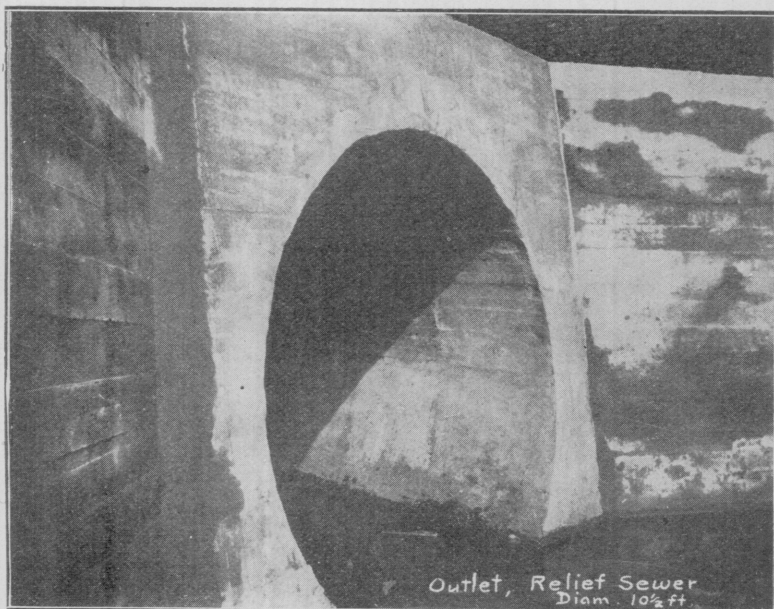


Fig. 38.—Outlet of the Relief Sewer, Columbus, Ohio.

One design was for the customary brick sewer, another for reinforced concrete and a third for plain concrete. But two contractors bid—number one accustomed to construct concrete sewers, number two unaccustomed to such construction. The bidder to whom concrete construction was strange bid much higher upon concrete than upon brick.

Number one's bid upon concrete was 86.6 per cent. of his bid for brick work, and only 85 per cent. of his competitor's bid upon brick work; while the bid of number two for concrete was 116 per cent. of his own bid upon brick work.

The lowest bid was accepted and the work is in progress. Figure 38 illustrates the outlet end of the 10½ foot sewer where it empties into the Scioto River.

ELECTRIC DUCTS.

Electric wires for light, telephone, telegraph and power are laid under ground in many of the large cities in tile or terra cotta pipes. In order to protect the wires and insulation from dampness, these pipes are imbedded in concrete as illustrated in Figure 39.

WATER PIPE.

In California, for a great many years, concrete pipe for irrigation and water supply purposes has been manufactured. As early as 1880, 18 inch to 24 inch pipes, 30 inches long were being made at Pomona, California, for the Pomona Land and Water Company, to bring the water supply from wells and tunnels onto their lands.

The Edison Electric Co., Redlands, California, have lately completed a gravity water power line 25,000 feet long, to their Mill Creek Power plant. It was constructed of 30 inch concrete pipe in 24 inch lengths; the shell of the pipe being $2\frac{3}{4}$ inches thick. The economy of this pipe over cast iron was largely due to the cost of freighting material to the line of work. The cement was hauled twenty miles direct from the works. Iron pipe would have been very expensive due to the great cost of hauling. Gravel was obtained right upon the work. The pipe was cast in metal forms, the concrete composed of 1 part Portland cement and 3 parts gravel, using $\frac{3}{4}$ gallon of water to a cubic foot of the mass. The pipe cost \$1.00 per foot to make and \$1.00 per foot to lay it. The pipes after being made were sprinkled frequently for about two weeks and then allowed to season several months before laying.

The water supply of Cuneo, Italy, is brought 5,900 feet through a concrete pipe $9\frac{7}{8}$ inches in diameter, under a head of 78 feet. The engineer originally estimated that the pipe would have to be $7\frac{1}{2}$ inches thick to withstand the pressure, but after careful tests decided to reduce the thickness to 3.15 inches. The pipe was built in 1888 or 1889 and is serving the purpose satisfactorily.

IRRIGATION DITCHES.

In 1891, an irrigation ditch at San Gabriel, California, 4 feet wide at the bottom, 6 feet wide at the top and 3 feet, 4 inches deep, was built with concrete sides and bottom. The concrete $2\frac{1}{2}$ inches thick, composed of 1 part cement to 8 or 10 parts sand and gravel, was laid directly upon the clean cut excavated bottom and sides of the ditch. The sand and gravel was used just as it came from the ditch excavation. After laying, the concrete was coated by brushing in upon the surface a neat cement cream. Two years afterwards it was reported to be in good condition.

About the same time the Gage Canal, near Riverside, California, was lined with $1\frac{1}{2}$ inches of cement-mortar composed of 1 part Portland cement and 4 parts sand. This irrigation canal is 22 miles long and belongs to the Riverside irrigation system. The work cost about \$1.03 per lineal foot of canal. It was reported to be in perfect condition after two years' service.

These cement lined irrigation ditches have much to commend them to the farmer and fruit raiser. They are in the first place economical,

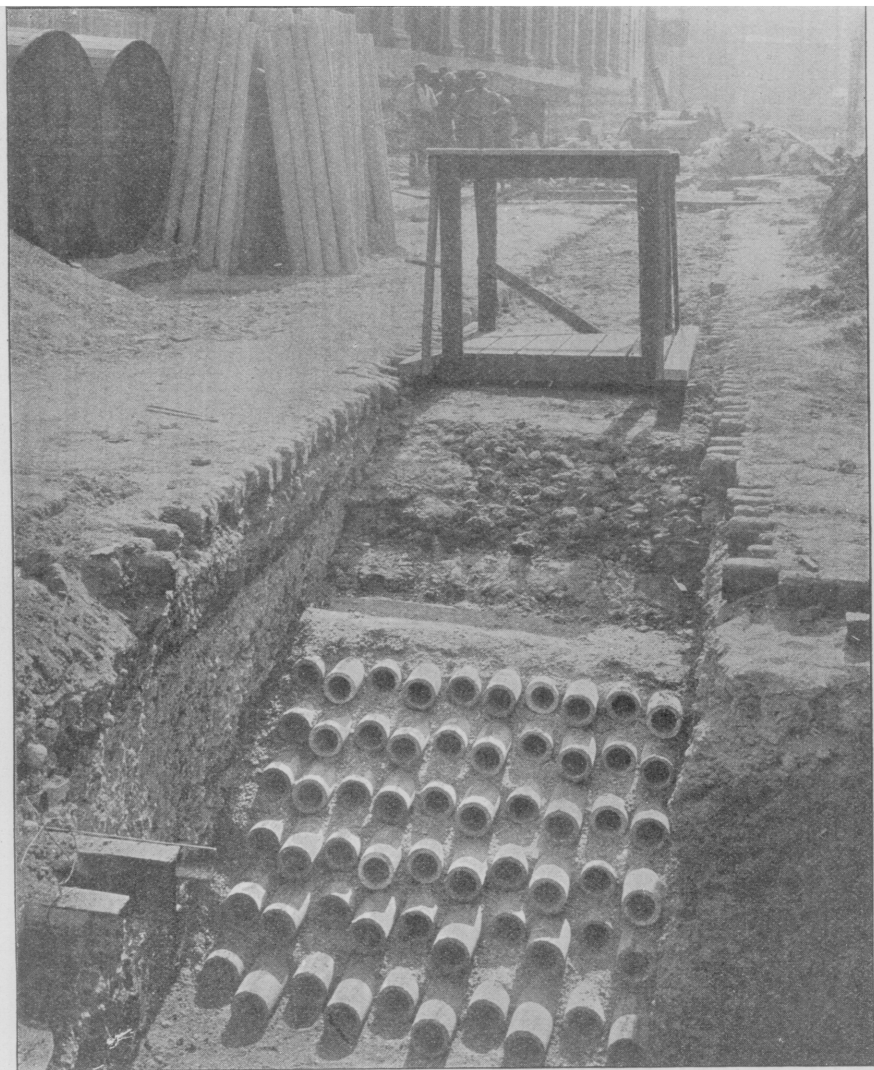


Fig. 39.—Electric Conduits Imbedded in Concrete, Cincinnati, Ohio.

saving an immense quantity of water from loss by percolation and from being taken up by useless vegetation along the line of the ditch. They prevent burrowing animals from destroying the ditch banks. They allow much flatter grades in the ditches, thus permitting larger territories to be brought within the irrigation sphere. As the surrounding ditch banks are not saturated, weeds do not grow along the canals to any great extent, therefore the farmer is not so seriously troubled with weed seeds being distributed over his farm in such immense quantities as formerly by the old open earth ditches. Within his farm limits the ditch presents a more pleasing appearance than the old weed bound ditch. It saves annually upon the cost of cleaning and repairing, which was originally required. Thus cement is a great boon to the western irrigator.

RESERVOIRS.

Mr. John Randall, of San Francisco, Cal., said he had coated a reservoir (in 1889) with a $1\frac{1}{2}$ inch coat of cement mortar upon the original sand and gravel surface. The mortar used was a 1 to 5 Portland cement mortar put on in one layer while the sand surface was moist. This structure had held water for four years against a head of 16 feet, without leaking.

In the water supply system for Aurora, Ill., there is a reservoir 150 by 140 feet in area, and 12 feet deep excavated through a layer of gravel and into a stratum of shattered limestone. This reservoir is lined with concrete 8 inches thick, except above the rock where the lining becomes a wall, reinforced at frequent intervals by heavy concrete buttresses about $5\frac{1}{2}$ feet thick at the base just above the rock. The concrete used was 1 part cement, 2 parts sand and 3 parts stone in the lining, and 1 part cement, 3 parts sand, 6 parts stone in the heavier masonry. This reservoir is illustrated in figure 40.

CISTERNS.

In 1876, the writer assisted his father in constructing a cistern in Pomona, Cal., which was lined with Portland cement mortar. The cistern was 7 feet in diameter and 11 feet deep, dug in a gravelly, loamy soil, and into a substratum of nearly pure sand and gravel. It was eventually coated with three coats of plaster. The plaster was composed of an imported Portland cement and sand. The proportions are not definitely remembered, but were probably about 1 cement to 3 sand. The first coat was plastered directly upon the clean cut gravel walls in a coat about $\frac{3}{4}$ inch thick. The second coat, about $\frac{1}{4}$ inch to $\frac{3}{8}$ inch thick, was plastered over the bottom and upon the sides to within about 4 feet of the top of the cistern. The interior surface was then washed with a neat cement cream. Water was turned in and entirely disappeared in twenty-four hours. Upon examination it was found that the weight of

water had settled the bottom away from the side walls for nearly $\frac{1}{2}$ inch. Another coat of plaster over the bottom and up the side walls for about 3 or 4 feet, followed by another wash of neat cement cream, remedied the trouble. The cistern was used constantly from that time until 1888, when a piped water supply replaced it. For a considerable period of time it was in service with 11 foot heads of water in it without any appreciable loss from leakage.

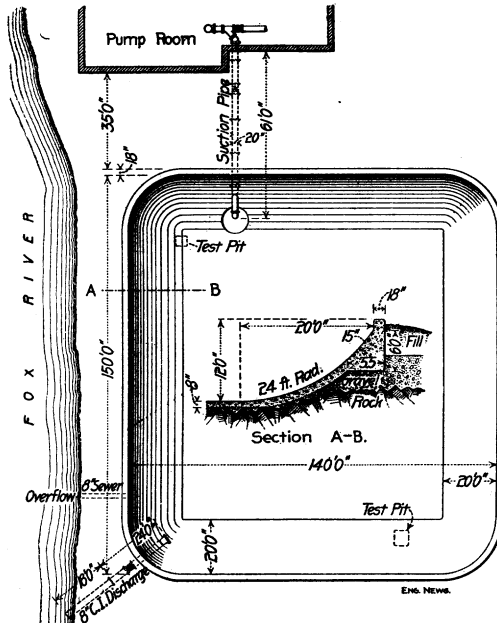
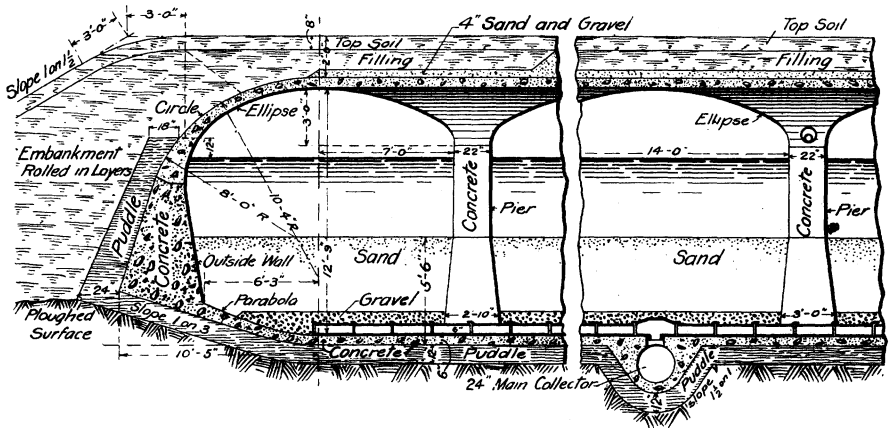


Fig. 40.—Plan of the Reservoir at Aurora, Ill.

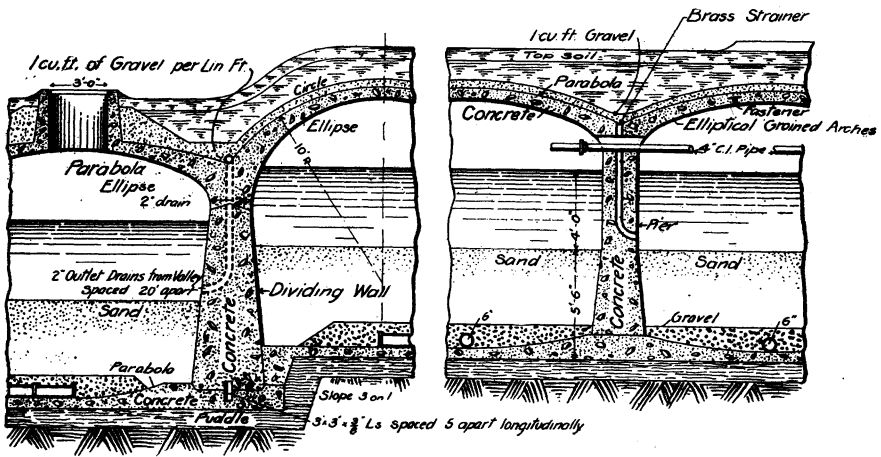
FILTER BEDS.

It is in underground structures that concrete shows to good advantage. Metal work would be subjected to serious corrosion. Brick or stone masonry would be either very expensive or else, if a cheaper quality of work and material was used, it would not be water-tight and durable. In filter beds, clear water basins, reservoirs and the like, impervious, non-corrosive materials should be used. Concrete comes nearer meeting all the requirements than any other material. For these purposes it has been extensively used for many years.

The Philadelphia filter beds illustrate its use for such purposes. The Philadelphia water system is divided into several supply stations with complete equipment at each station. For the purpose of this article it will be sufficient to describe one of the filter beds at the Belmont plant. There are eighteen filter beds at this station varying in dimensions from 166 by 196 feet to 120 by 272 feet, each filter bed covering approximately



SECTION THROUGH CROWN OF ARCH



SECTION THROUGH PIERS

SECTION THROUGH CROWN OF ARCH

Fig. 41.—Cross Section of the Filtration Chambers, Philadelphia, Pa.

$\frac{3}{4}$ of an acre. These basins are built into the ground and covered over with sand, gravel and earth, and then sodded. The floors and arched roofs of concrete are about 6 inches thick. The side walls vary from about 4 feet, 2 inches thick at the base, to 12 inches thick at the spring line of the roof. The roof consists of groined arches resting upon the walls and a series of concrete piers 22 inches square at the top and 34 inches square at the base. The arches have a 14 foot span, 3 foot rise and are 6 inches thick at the crown and 21 inches thick over the piers. Over the arches are spread 4 inches of gravel to act as a draining medium to carry all collected storm water to small inlets situated over each pier, allowing the

surface percolation to be admitted to the filter beds and to be filtered with the regular supply. Concrete manholes opening to the surface are constructed at regular intervals to allow light and ventilation during cleaning and reconstruction of the sand beds. Figure 41 shows a section through the filter bed in the Roxborough plant, Philadelphia, which is similar to the Belmont plant.

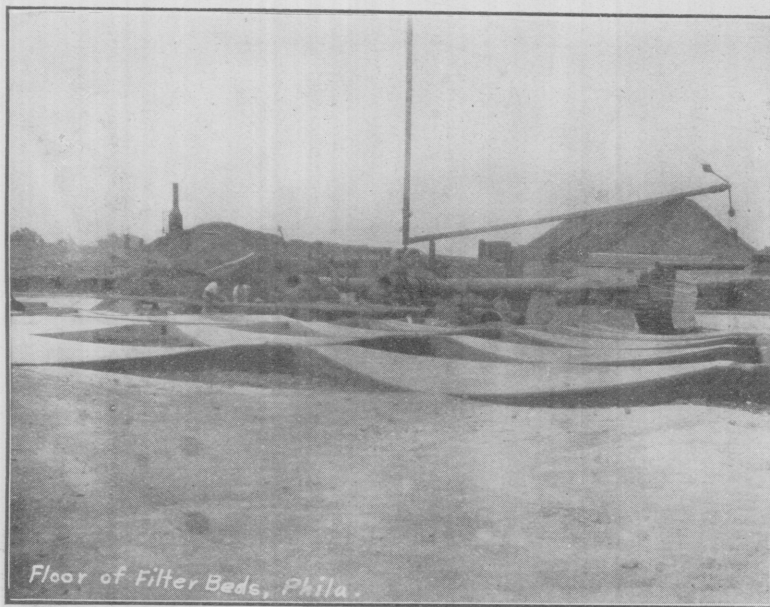


Fig. 42.—Floor of Filtration Chambers in Process of Construction, Philadelphia, Pa.

Figures 42, 43 and 44 illustrate the progressive steps in construction of the filter plant.

DAMS.

Concrete is especially useful in the construction of dams. Usually these must, of necessity, be located at points not easily accessible for securing cut stone and therefore for economy, concrete presents the best available material. Usually, however, stone is in abundance in some form which can be crushed into concrete size. It is now known that crushed stone screenings are as good as sand for a fine material to fill voids and make mortar, so that all the material requiring transportation to the site is cement. Solid monolithic structures can thus be erected with great economy.



Fig. 43.—Columns for Supporting Roof of Filtration Chambers, Philadelphia, Pa.

Otay Dam.—The Otay dam, figures 45 and 46, near San Diego, Cal., illustrate such a use of cement. This dam is 350 feet long, with a greatest height of 84 feet above the foundation. It is constructed in the



Fig. 44.—Interior of Completed Filtration Chamber, Philadelphia, Pa.

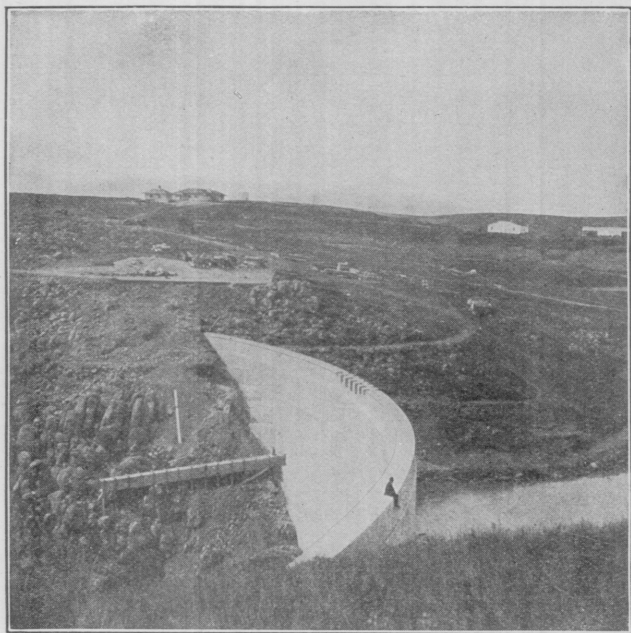


Fig. 45.—Otay Dam, San Diego, Cal.

arched form, arching up stream with a radius of 359 feet. The maximum thickness at the bottom for 14 feet in height is 24 feet, decreasing in steps until the top 5 feet is but 4 feet thick. The proportions of concrete are also graded in strength from the bottom toward the top. The bottom 31 feet is of concrete composed of 1 part cement, 2.1 parts sand and 3.4 parts crushed stone; from elevation 31 to 36 it is of 1 part cement, 3.2 parts sand and 4.2 parts stone; from elevation 36 to 75, it is of 1 part cement, 3.33 parts sand and 4.6 parts of stone. The bottom portion is reinforced for water tightness with steel plates. From the point where the steel plates cease to the top, the dam is reinforced by horizontally laid steel railway cables, $1\frac{1}{4}$ inches in diameter, spaced 2 feet apart vertically.

Las Ninfas Dam.—The United States Army officers built a concrete dam near Guatanamo, Cuba, shortly after the American-Spanish war, which stood a remarkably severe test a short time after its construction. The dam was in a narrow gorge, and was 24 feet long, 15 feet high and 2 feet thick with a straight crest. A sudden heavy rain in the hills raised the water so that it passed over the dam to a depth of 10 feet upon the crest, no damage being done. The concrete must have acted as a beam in this case to have withstood such a weight of water.

Some of the larger dams now under construction in the eastern portion of the United States are being built of concrete in which large irreg-

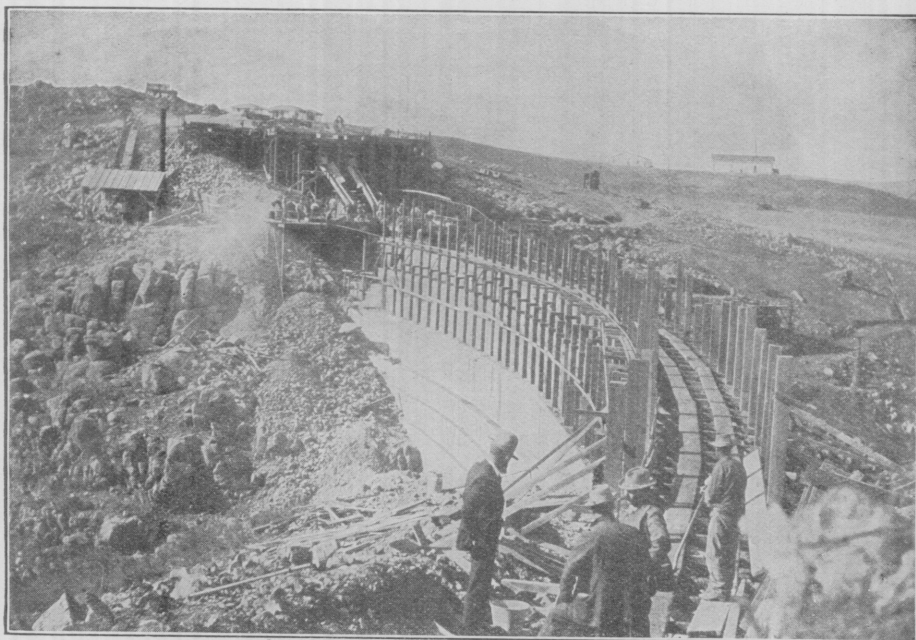


Fig. 46.—Otay Dam, Showing Contractor's Plant, San Diego, Cal.

ular stones are imbedded. (Figure 47.) These stones make about one-half of the volume of the dam. Such cyclopean masonry might be termed titanic concrete.

The opportunity to reduce in cost of construction by adopting open or buttressed sections in concrete, such as are described elsewhere in this article, will bring concrete more prominently to the front in the future than it has been in the past for large dams.

Apple River Dam.—Another feature of concrete is in the facing of old masonry dams or soft stone masonry cores in new dams. The Apple River dam for the St. Croix Power Company of St. Paul, Minn., illustrates its use in the latter form. This dam erected across the Apple River about 27 miles east of St. Paul, was in a very rough country where the only available building stone was a brown sandstone easily eroded by running water. It was decided to erect the core of the dam of this sandstone laid as uncoursed rubble with Portland cement mortar, composed of 1 part cement to 3 parts sand. This core was then encased with from 18 inches to 2 feet of concrete having the following proportions: 1 part Portland cement, 3 parts sand and 4 parts broken stone. The dam is 350 feet long with a central spillway 108 feet long over the crest of the dam. The dam is built in arch form up stream with radius of curvature equal to 450 feet. It is 47 feet high and has a base width or thickness of 38 feet. No cracks or leakage had appeared after a year's service. Figure 48 shows a cross section of the dam.



Fig. 47.—Cyclopean Masonry, Boonton, Dam.

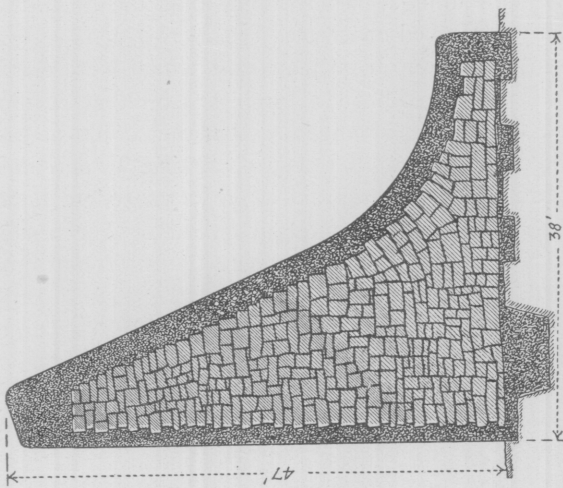


Fig. 48.—Section of Dam of St. Croix Power Co., illustrating the Use of Rough Stone in the Center.

Birmingham Reservoir.—“The new waterworks scheme for Birmingham, England, now on the eve of completion—the greatest water scheme that has ever been attempted—a work involving the use of many *thousands of tons* of Portland cement. The water is first stored amongst the mountains in six cement reservoirs, the total storage capacity of which is 17,360 million gallons, and they cover an area of 1,499 acres. From the storage

reservoirs the water is conducted 80 miles across country, through mountains and over valleys and rivers by the aid of cement bridges, culverts, walls, tanks, tunnels, etc., to the large cement service reservoirs and filter beds shown in illustration. (Figure 49.) Of cement concrete work there are $8\frac{1}{2}$ miles of tunnels, 35 miles of cut and cover, and $34\frac{1}{2}$ miles of iron pipes—the cut and cover and tunnels being 8 feet in diameter.

"The site of this extensive concrete reservoir, shown above, covers a space of three-quarters of a mile in one direction and $1\frac{1}{4}$ miles in another. The walls, formed entirely of Portland cement concrete, are 16 feet thick at the base and about 35 feet in height. The water is delivered from this reservoir into a series of 18 quadrangular filter beds, ranging from 150 to 220 feet square, and forming a total filtering area of 67,000 square yards. These filtering beds are also wholly constructed of Portland cement concrete."—*Cement*.

TUNNELS.

Among some of the many tunnels in which concrete has been used as a lining, probably none will better illustrate its usefulness than the Cascade tunnel upon the Great Northern Railway located where this railway crosses the Cascade Mountains in Central Washington. The tunnel was under construction from 1897 to 1900. It is 16 feet wide and $21\frac{1}{2}$ feet high in the clear. The lining varies from 24 to 42 inches in thickness and is monolithic, non-re-enforced concrete.

The concreting was done from platforms which were erected so that work trains could pass beneath. The arch was built in 12 foot sections. The centers were of planking arranged so that they could be easily moved forward and jacked up to the proper position again. Concrete plants were erected at both ends of the tunnel and were arranged to handle all the material from the crusher to the mixer by gravity. The best rock taken out of the tunnel was crushed for the concrete, the proportions of which were 1 part Portland cement, 3 parts sand and 5 parts broken stone. There were 95,000 barrels of cement used or 7 barrels per lineal foot of tunnel. The average monthly progress of lining the tunnel was 1,115 feet, with a maximum length of 1,713 feet for the best month's work. The best day's work was 32 feet of completed lining.

The total length of the tunnel is 13,813 feet. It saves nine miles of switch backs, 677 feet of elevation and 2,332 degrees of curvature. No statistics as to cost were given with this article.

Peekskill Tunnel.—A writer in *Engineering News*, of December 17th, 1903, gives the itemized cost of a concrete lining in a short length of tunnel upon the New York Central and Hudson River Railroad north of Peekskill, New York. He itemizes the cost under the various heads of material, lumber for forms, tools, freight, power, labor, etc., for about 2,000 cubic yards of concrete. It amounts to \$10.72 per cubic yard for a

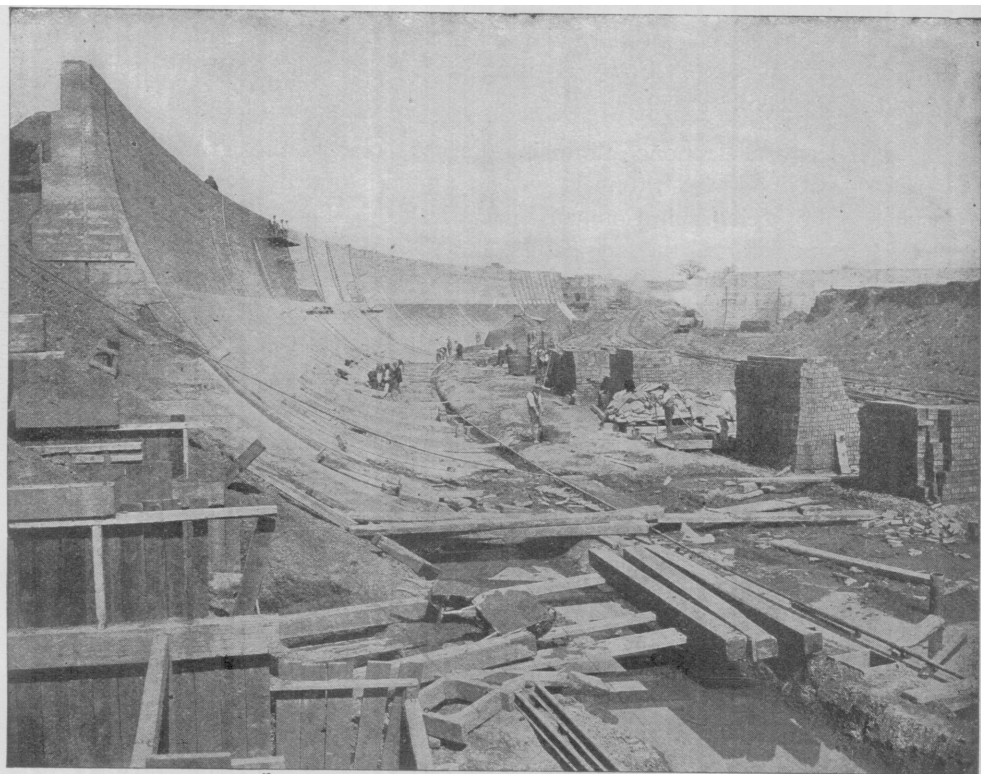


Fig. 49.—Reservoir at Birmingham, England, in Process of Construction.

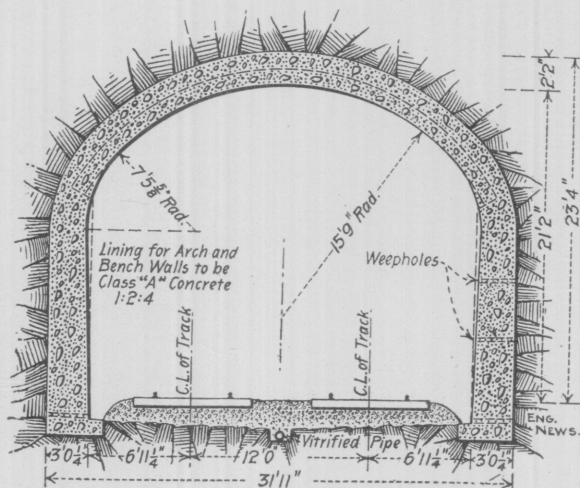


Fig. 50.—Section of Peekskill Tunnel, Showing Concrete Lining.

concrete composed of 1 part of cement, 2 parts of sand and 4 parts of broken stone. The portal head walls were of 1 part of cement, 3 sand and 6 broken stone. Figures 50 and 51 show south portal and section of the Peekskill tunnel.

Chicago Telephone Tunnels.—Perhaps one of the largest, at any rate one of the longest, tunnels ever attempted is that of the Illinois Telephone and Telegraph Company in Chicago. The trunk tunnels are $12\frac{3}{4}$ by 14 feet and the lateral tunnels 6 by $7\frac{1}{2}$ feet in the clear. Their total length when completed will be about sixty miles. Up to September 1, 1902, twelve miles had been constructed and the work was advancing in fourteen headings at an average rate of 328 feet per day for completed work. About 1,500 men were employed in three shifts working eight hours each. The crown of the tunnel varies from $24\frac{1}{2}$ feet to 35 feet below the surface of the street. The tunnel is being driven through stiff, blue clay without any support being required. Semi-circular draw knives are being used to cut down the clay. It is then shoveled into the cars which transfer it to the shafts where it is lifted to the street above. The ribs used for the forms are of channel iron, 3 inch channels for the laterals and 5 inch channels for the trunk tunnels. Two inch planks are used for lagging. The concrete consists of 1 part Portland cement and 5 parts crushed limestone, screenings and stone below $\frac{3}{4}$ inch in size being used, or gravel and sand being used in place of crushed stone. At curves and intersections, the concrete is strengthened by being made in proportions of 1 cement to 4 of stone or gravel. The floor is first put in place, the ribs are then set up and braced and the lagging suspended upon the frame work of ribs. The concrete is rammed behind the forms in layers and as each layer is finished, lagging is added until the key of the arch is reached—here short lagging is used and the concrete rammed into place from the end of the wall. After the forms are removed the walls are plastered to make them smooth and impervious. The floors of the trunk tunnels are 21 inches thick, with side walls 18 inches thick, while in the laterals the floors are 13 inches thick with 10 inch side walls. In the twelve miles of work done, 175,000 cubic yards of excavation have been removed and 90,000 barrels of cement have been used in the work. The tunnel was kept in most scrupulous cleanliness by the superintendent. The writer was never in a cleaner tunnel in his life. One could travel miles through the tunnel, going right into the working headings, and not soil a dress-suit nor injure patent leathers. At every street intersection street name plates are set into the concrete walls so that it is much easier to determine one's location in the tunnel than in the streets of the city above. Figures 52, 53 and 54 show a section of the completed tunnel, one of the ribbed forms for the trunk tunnel showing method of bracing the forms and a completed intersection. Figure 53 also shows the diaphragm plates used at the end of a section to keep the concrete in place.

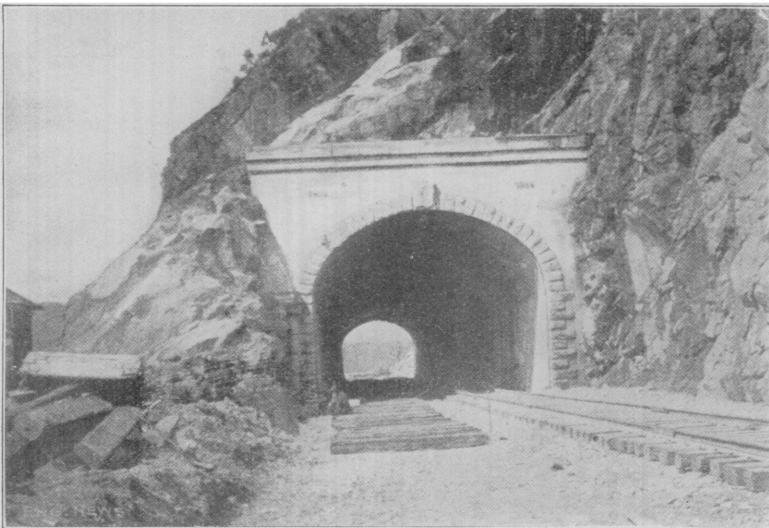


Fig. 51.—South Portal of Peekskill Tunnel, New York.



Fig. 52.—View of Four-Way Intersection, Tunnels of Chicago and Illinois Telephone Company.

TIES AND RAIL BEDS.

The question of street and street railway maintenance in large cities has become one of increasing importance as the traffic demands have so rapidly increased during the past thirty years. The old forms of street

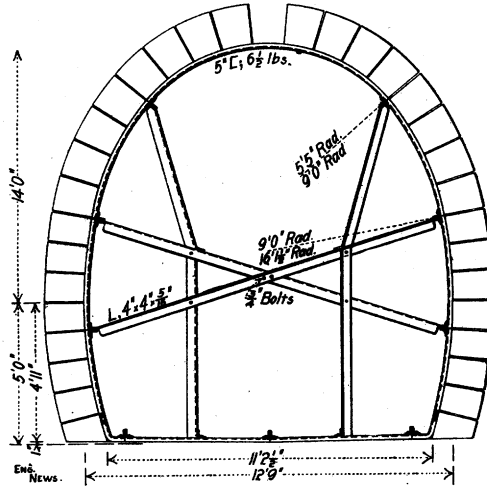


Fig. 53.—Frame and Forms for Lagging Tunnels of the Chicago and Illinois Telephone Company.

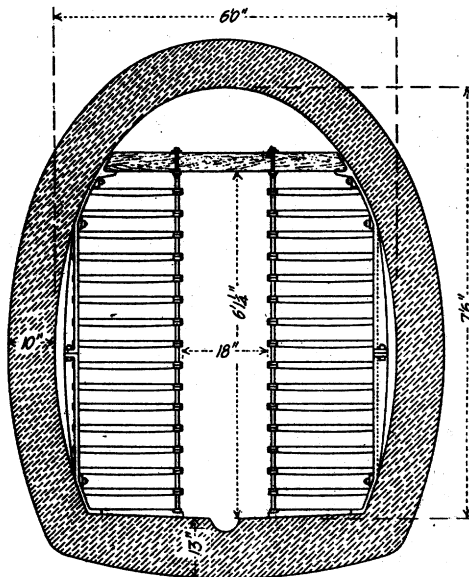


Fig. 54.—Cross Section of Finished Tunnel of the Chicago and Illinois Telephone Company.

railway construction were disastrous alike to street paving and to smooth riding tracks. Wooden ties, unsupported except by poorly tamped soils,

which, at best, could not make firm support, allowed the track to vibrate and undulate, shattering the street paving. Great opportunity was thus given for the entrance of storm water into the sub-foundation, making it still more unstable both for track and paving, until the street and track were both wrecks. To add to this, the rotting of the wooden ties required the continual tearing up of the streets in order to replace them and to keep the track in sufficient repair so that traffic could be maintained at all. Such conditions became unbearable in many of the important business streets of great cities, both to vehicle and railway traffic, and a remedy was sought. It is not necessary to follow the path of the search parties. It is sufficient to say that the remedy was found, as in many another search, in concrete.

Concrete has been used in various ways as a foundation bed for wooden ties, as stringers beneath the rails only, as concrete ties on ordinary tamped earth beds or gravel beds, and as solid concrete road beds imbedding the rail directly within the mass of concrete.

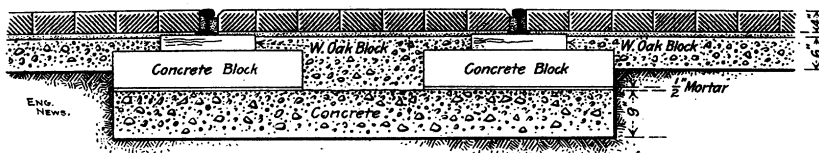


Fig. 55.—Section of Track Showing Use of Concrete Ties, Pere Marquette Railway.

† Figure 55 illustrates the form used on the Pere Marquette R. R., in Bay City, Michigan. A concrete foundation beneath the entire track is first laid, upon this, well made concrete blocks, 7 inches by 9 inches by 36 inches are laid 33 inches center to center in a bed of cement mortar and then surrounded with concrete and the concrete is carried up to within 1 inch of the base of the paving block. Upon the concrete block is placed a 3 inch white oak spiking block to which the rails are spiked. Concrete is also filled in around the web of the rail sufficiently to leave flange way between the rail and the paving block.



Fig. 56.—Street Railway Section Showing Concrete Rail Supports.

In Minneapolis and St. Paul, * the rail is imbedded directly in the concrete as shown in Figure 56. The rails are kept evenly spaced by metal

† *Eng. News*, Aug. 28, 1902.

* *Eng. News*, Feb. 28, 1903.

tie rods spaced at frequent intervals. The shape of the concrete which forms the rail bed is varied by different engineers, but the same result is obtained. The track and paving become one solid whole. The following estimate of the cost of one mile of such track, using a grooved rail, is given by Mr. B. J. Arnold, M. Am. Inst. Elec. E. Many of the prices used in the estimate will vary, of course, according to the market and local conditions; this estimate was made for Chicago, early in 1903.

Estimated Cost of One Mile of Grooved Rail Track with Concrete Beam Support.

Excavation and hauling, 2,000 cu. yds. at \$1.00	\$ 2,000 00
Concrete beams, 800 cu. yds. at \$6.00	4,800 00
Steel rails, 120 lbs. per yard, 188.57 tons at \$41.00	7,731 00
Hauling rails to street at \$1.00	189 00
Tie rods, 700, at \$0.25	175 00
Cast welded joints, 176, at \$5.00	880 00
Cross bonding	10 00
Track laying, cleaning street, etc.	1,501 00
Special track work per mile of single track	4,500 00
Engineering, supervision and administration at 10%	2,179 00

Total cost of track exclusive of paving..... \$23,965 00

ROAD FOUNDATIONS

For years concrete foundations for paved streets have met the decided approval of municipal engineers. The engineer who fails to consider the foundation to be one of the most important essentials of a well paved street fails to secure economy and durability in the streets he paves. Better an inferior wearing surface upon a first class, solid, impervious foundation, than a high grade wearing surface upon a yielding pervious foundation. In the first case only the wearing surface needs renewing after a short period, while in the latter case the whole construction including the road-bed must be overhauled in order to secure a decent street. Of all the foundation materials employed, none so nearly meet all the requirements as does well laid concrete. It is rigid, distributing the load of traffic to a large bearing surface of soil; being rigid, it does not allow deformation of the wearing surface and the consequent abrasion due to such deformation; it prevents water reaching the soil of the road-bed, and thus the subgrade gives firm support to the foundation. It is easily and perfectly repaired when it becomes necessary to cut into a street for subsurface connections of any kind. It is durable to the maximum limit of man's observation. It is not much more expensive than a well rolled broken stone or gravel foundation, which is next in importance for such purposes.

The thickness required varies from 4 to 8 inches according to the traffic and to the character of the subsoil. Six inches is the usual depth

and for all ordinary circumstances this is ample if good concrete is used. Both natural and Portland cements are used for foundation work, but the writer prefers to use Portland cement. Different engineers vary greatly in the proportions used. The character of the soil beneath has some weight in the choice of the proportions.

With natural cements these proportions may vary from 1 cement, 2 sand and 3 stone, to 1 cement, 3 sand and 6 stone. When Portland cement is used, the limits are from 1 cement, 2 sand and 5 stone, to 1 cement, 5 sand and 10 stone. Under all conditions the writer should prefer to use a richer mixture than the last named limit. The concrete should be well mixed and compacted, and rather wetter than concrete used in walls.

Some of the later concrete foundations put down in Columbus, Ohio, have been of 1 cement, 4 sand and 8 broken stone; these proportions appear to make an excellent foundation.

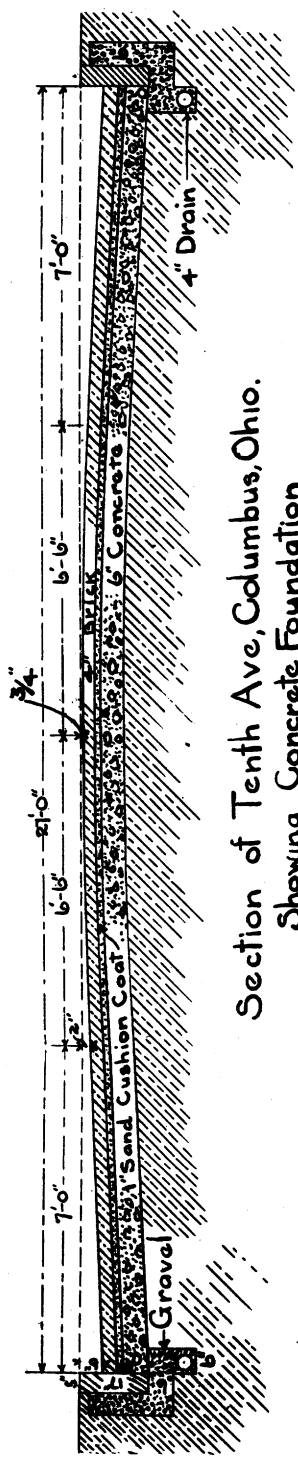
Figure 57 shows a section of Tenth avenue, Columbus, Ohio, which is paved with brick block upon a concrete foundation. This concrete foundation costs from 70 to 75 cents per square yard. The labor of mixing and laying the concrete cost on an average 15 cents per square yard.

The cost of concrete foundation was carefully kept in Toronto, Canada, as follows:

	Cost per cu. yd.
Cement at \$2.77¾ per bbl.	\$2.15
Broken stone at \$1.91 per cu. yd.	1.43
Gravel and sand at \$0.80 per cu. yd.	0.21
Labor at 15c. per hour	1.04
Total per cu. yd.	\$4.83
Or, with concrete six inches deep, 80½ cents per square yard.	
The concrete used in this case was 1 cement, 2½ sand and 7½ stone.	

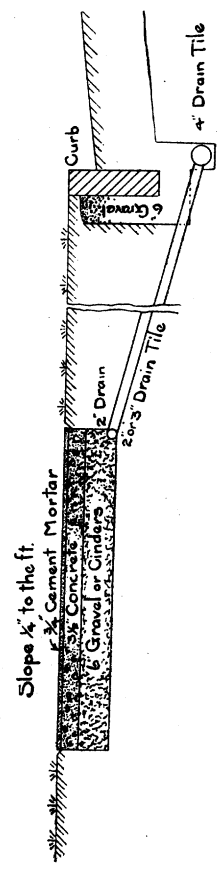
PAVED STREETS.

While concrete has not been used extensively as a surface paving material for streets, it has been used quite satisfactorily in some alleys in Philadelphia, a couple of streets or courts in Grand Rapids, Mich., and on four streets at Bellefontaine, Ohio. The streets in Bellefontaine were laid in 1892 and 1893, and are in excellent condition today. The concrete was laid upon a well compacted road-bed in two layers, the foundation layer 4 inches thick, and the surface layer 2 inches thick. In two of the streets the foundation concrete was composed of 1 part Portland cement to 5 parts coarse gravel, and the surface coat 3 parts cement to 5 parts coarse sand. In the other two streets the proportions were: Foundation, 1 cement to 4 parts gravel, and surface coat, 1 cement to 1 sand. Both top and bottom layers were cut into blocks about 5 or 6 feet square and tarred paper used in the joints to give room for expansion. The sur-



Section of Tenth Ave, Columbus, Ohio.
Showing Concrete Foundation

Figure 57.



Section of Concrete Sidewalk
Figure 60.

face layer after being thoroughly rammed and floated was indented with an imprint roller in order to give a better foothold for horses. While some repairs have been made, the streets do not show any patchy appearance and along the sides the surface has not worn enough to obliterate the imprint marks which are clearly shown in figure 58. The worst worn place in the streets is shown in Figure 59 where the street was narrow and drained toward the center. Here the wheels have followed in the lines cut to demark the blocks, and have worn the cutting lines about 2 inches deep. The streets cost \$2.15 per square yard. There appeared to be no complaint against the streets on account of slipperiness or because of the jar or lack of elasticity. Such streets are easily cleaned and dry up quickly after storms.



Fig. 58.—Concrete Pavement at Bellefontaine, Ohio. In the Foreground Will Be Seen Surface Marks Not Destroyed After Years of Use.

SIDEWALKS.

Concrete sidewalks have been used many years. There is no one of the requirements for a good sidewalk which concrete does not completely fulfill. It makes a smooth walk and yet it is not slippery. It is durable, wears evenly, does not absorb water seriously, dries up very quickly, does not glaze over with ice as quickly nor as completely as does brick, does not flake up nor disintegrate under action of frost. In fact, it is ideal. In some cities there is a prejudice against concrete walks because unprincipled or ignorant contractors have done poor work, and like poor work in any business, it has not proved satisfactory. Wherever

proper work has been done, concrete walks have grown in favor very rapidly. In some towns ordinances have been enacted requiring concrete walks and not allowing any other kind of walk to be laid within their limits. A good concrete walk should have a $3\frac{1}{2}$ inch base with a one inch wearing surface. Upon gravelly or well drained soil this will be sufficient, but in clayey or heavy soils it is best to construct the walk with a subfoundation consisting of from 4 to 10 inches of well compacted gravel or cinders.

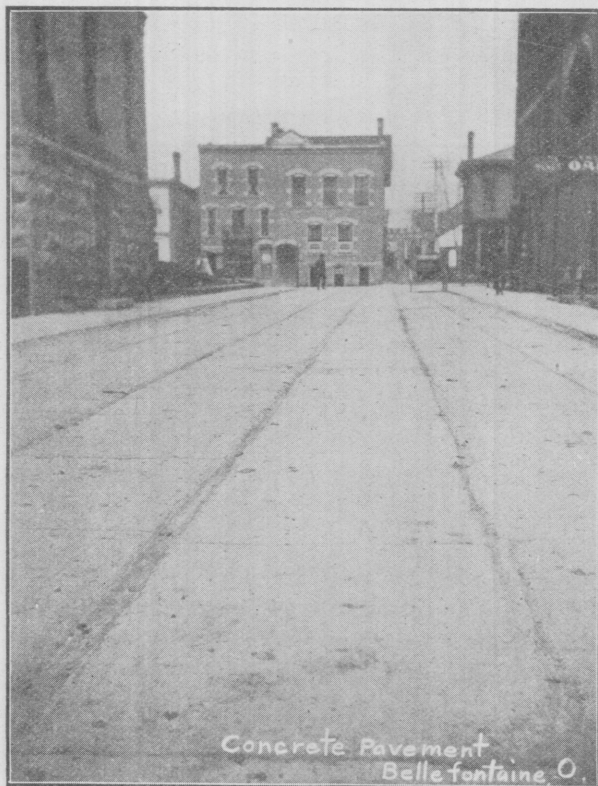


Fig. 59.—Concrete Pavement at Bellefontaine, Ohio, Showing Longitudinal Wheel Marks.

Drainage is also necessary in heavy soils in order to prevent heaving of the walk during the winter weather. Another precaution that should be observed is to cut the walk into blocks about 5 feet square, taking pains to cut entirely through both foundation and surface layers, so that any heaving from frost or settling due to poorly compacted sub-bed, will not break the individual stone, but simply move the block at the cutting line. The attempt to cheapen the work by using a natural cement for the base and a Portland cement in the wearing surface is ill-advised economy.

It is quite questionable whether a perfect union between the two masses of concrete can be secured. The gain in cost is so small when the question of the greater allowable proportion of aggregate with the Portland cement over that with natural cement is considered, that it does not pay to risk the character of the work to make the gain.

The cost of cement walks, well constructed, in 1896 to 1898, varied from 11 to 14 cents per square foot. In 1902 and 1903, prices of material and labor being higher, the same class of work cost from 14 to 17 cents per square foot.

As to the life of a first class concrete walk, there appears to be no limit. The writer knows of one walk that has been down some twenty-one years or more that is as good today as the day it was laid.



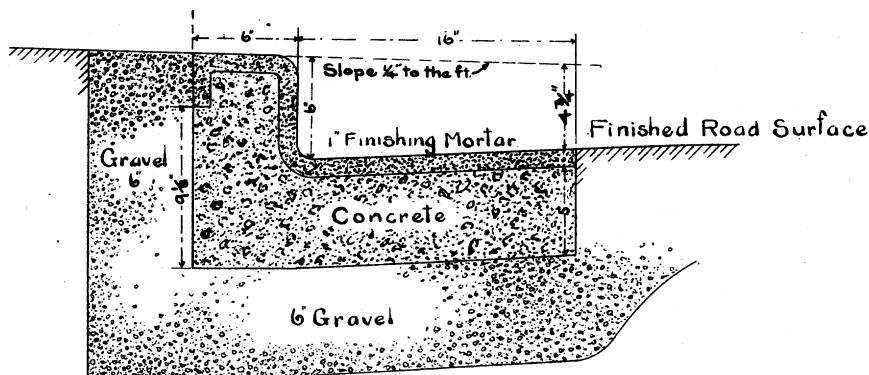
Fig. 61.—Concrete Sidewalk Built in 1880 at Conneaut, Ohio.

One of the walks along the Capitol Block in Indianapolis has been down over thirty years. It was constructed of excellent material, but with no special attention to the preparation of the sub-bed, consequently water has percolated into the soil beneath and heaved the blocks badly and they have become broken. The blocks are cut about 18 or 20 inches square with lines running diagonally across the walk. Where they have had reasonable support, however, they are still in good condition. If

the walk had been constructed as the better class of walks is today, it would have remained in perfect condition. It seems almost incredible to believe that people can go on year after year stumbling over miserably irregular brick walks, when smooth, regular concrete walks are obtainable. Figure 60, page 112, shows a section of a concrete walk. Figure 61 shows a well preserved old concrete walk.

CURBS AND GUTTERS.

A much later application of concrete than that of sidewalk construction is its use for curbs and gutters. So many of the natural stones when used for curbs absorb water and disintegrate under frost action. Limestone is especially subject to disintegration because of its lamination. Sandstone wears rapidly at points where wheels rub. In some parts of our country neither limestone nor sandstone can be obtained at a reasonable price, thus the demand for some good substitute has arisen.



Section of Combined Concrete Curb and Gutter

Figure 62.

It has been found very easy to put in the plain concrete curb, and it has proved very durable and at the same time has added much to the appearance of the street. Another problem that the road engineers have had to solve is the building of a gutter that will be smooth enough not to retard the flow of storm water upon very flat grades and at the same time so impervious, durable and tough that it will not rot out under continued dampness nor wear out quickly under usage. Cobblestone, brick and stone block retard the flow of water. Asphalt and coal tar rot or disintegrate under the action of water. Concrete once more fulfills all the requirements. By combining the curb and gutter into one monolithic whole, several difficulties are avoided. The displacement of the curb, due to frost upon one side or the expansion of the street upon the other, is greatly reduced. Shrinkage and expansion do not cause cracks along the face of the curb,

thus allowing storm water to seep into the foundation and road-bed to create havoc. Debris, which usually collects in the gutters, is more easily carried along by the storm water, hence a cleaner looking street is the result. The general appearance of a combined curb and gutter is more pleasing to the eye. So once more concrete has found an opportunity to usurp the place of other building material. Figure 62 shows a section, with average dimensions, of a combined curb and gutter as used upon Ninth avenue, Columbus, Ohio. Such a curb and gutter costs about 75 cents per lineal foot.

FENCE AND FENCE POSTS.

Around the old village of Woodruff Place, now within the corporate limits of the city of Indianapolis, is a concrete fence, not a wall, but a fence with posts and stringers with large concrete balusters or palings. The posts are about 24 inches by 36 inches in cross-section and 4 feet high set every 10 feet. A top rail 20 inches wide and 8 inches thick runs from post to post, with a base rail quite near the ground. Connecting the two rails and spaced 18 inches center to center are ornately shaped balusters. The fence is not in the best of repair, but it has been in place for thirty years or more and is in fair condition considering its age and the probable manner of construction.

POSTS.

At the zoological garden in Washington, the officers in charge have put concrete bases on the iron posts which are to be used in fencing in the larger wild animals. The advantage is very apparent. Iron would rust out quickly, and having rusted, might give way at some time without any warning, allowing valuable or dangerous animals to get away. With the concrete base upon the post several things are gained. First, the enlarged base gives more firmness to the post; second, the iron below ground is protected from moisture and from action of soluble chemicals in the soil, and third, as the concrete comes to the surface the post above the concrete is open for inspection and any weakness or corrosion can be detected before harm is done. These posts consist of small iron pipes or bars set in the center of the concrete bases which are 12 inches square and 24 inches deep.

MILE POSTS.

The Chicago and Eastern Illinois Railroad* has adopted a concrete mile post. The post is 8 inches square and 8 feet long, standing 4½ feet out of the ground. The figures are 3½ inches high and the letters 6 inches high, both being recessed ¼ inch into the post. The post weighs 498 pounds.

The sides of the form are plastered ½ inch thick before the ordinary concrete is put in. A special feature of the post is that the face contain-

**Eng. News*, Jan. 1, 1903.

ing the letters is plastered with neat cement colored black by the addition of $\frac{1}{4}$ pound of lamp black to 1 quart of cement mixed in water. The letters and figures are then painted white. The concrete is composed of 1 part cement, 1 part sand and 2 parts crushed stone.

The cost of the post is as follows :

$\frac{1}{4}$ barrel of cement, at \$2.00	\$.50
267 pounds of crushed stone	.01
133 pounds of sand	.01
$1\frac{1}{2}$ hours of labor, at 15c.....	.20
Carpenter, changing letters, $\frac{1}{2}$ hour, at 25c.....	.08
Coloring in cement	.02
Total cost of post	\$.82

Figure 63 illustrates this post.

There are now several post manufacturing concerns which make concrete posts, but all are reinforced by steel and will be described in the next chapter.

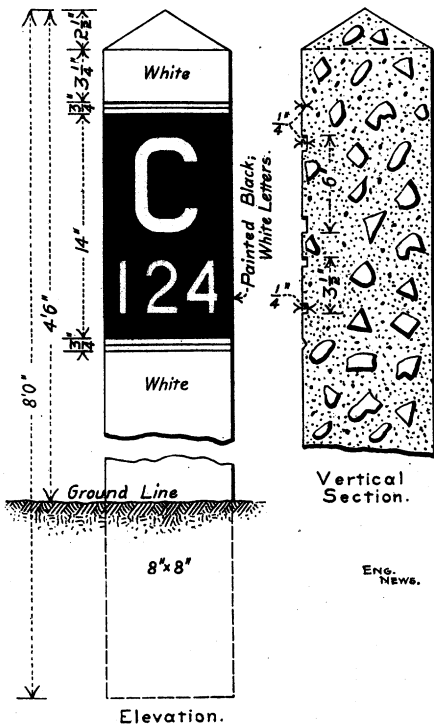


Fig. 63.—Concrete Mile Posts on the C. & E. I. Railroad.

TELEGRAPH POLES.

The manufacturing of concrete butts for telegraph poles is one of the latest novelties in the use of cement. It is well known by those who

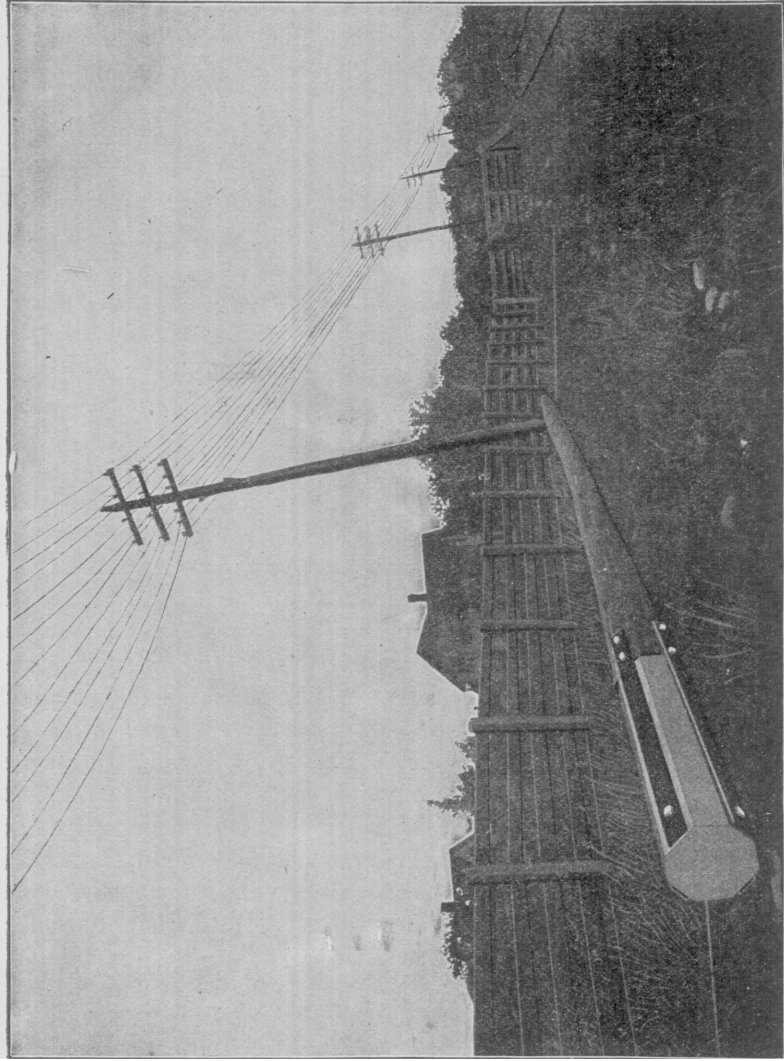


Fig. 64.—Concrete Butt for Telegraph Pole.

are observant that when telegraph or telephone poles have to be replaced, it does not always mean that the whole pole has rotted away, but just that portion sitting in the ground. Sometimes the poles can be removed to a country line and reset by having the base sawed off; the balance of the pole being perfectly sound. The cost of renewing poles, rewiring, etc., is expensive. To avoid much of that trouble and expense this industry provides concrete bases cast in octagonal forms with four iron strips bolted to opposite faces extending a foot or more above the concrete. The rotten butt of the pole can then be sawed off, the pole set a couple of feet to one side, the concrete butt set firmly in place and the pole set into the socket between the iron strips and firmly bolted to its new base. No wiring need be touched nor communication interrupted in the least. The pole when thus equipped is better than new, because it will not rot out at the base again. If from extreme age or from special disaster the poles need replacing, poles five feet shorter than otherwise required can be used, thus adding materially to the amount saved. Such concrete butts have been in use for three years, giving good satisfaction. Figure 64 shows such a butt bolted to a pole.

BURIAL VAULTS.

Concrete burial vaults are being made, in sections, so that they can be shipped to any point, set up in cement, and thus provide water-tight and nearly air-tight receptacles for the casket. The pieces are not large, so that they are easily handled. They are all grooved and ribbed so that they fit together well, and neat cement paste is used in all the joints to make a perfectly tight vault. The roof is made in arched form with beveled edges fitting into the V shaped bevels upon the top end of the side pieces.

The inventor claims two objects are served by this kind of a vault: A better protection to the bodies of the dead, and a sanitary safeguard provided for the living. It serves one of its most useful purposes in the exhumation and reinterment of bodies. It is not so cumbersome but that it can be moved bodily without removing the interior casket, the cement-joints and the bevel rib feature making the vault one solid piece of stone to be moved. Figure 65 illustrates the Lyon's burial vault, the shape of the pieces, and the method of fitting them together.

FURNITURE.

Mr. W. N. Wight of Westwood, N. J., has still further extended the use of concrete by making various articles of house and stable furniture. Among the articles is an ice chest with an opening to put in the ice from the outside of the house, while the provisions and food are placed in the cooling chamber from within the house. Another article is a concrete fruit closet for canned goods. Outside, he has built a neat dog

kennel which is comfortable, durable and easily kept in sanitary condition. At his stable, he has constructed a concrete stove on which to cook the food for his stock. In all this work he has used woven wire netting with a concrete of 1 cement, 2 sand and 5 cinders.

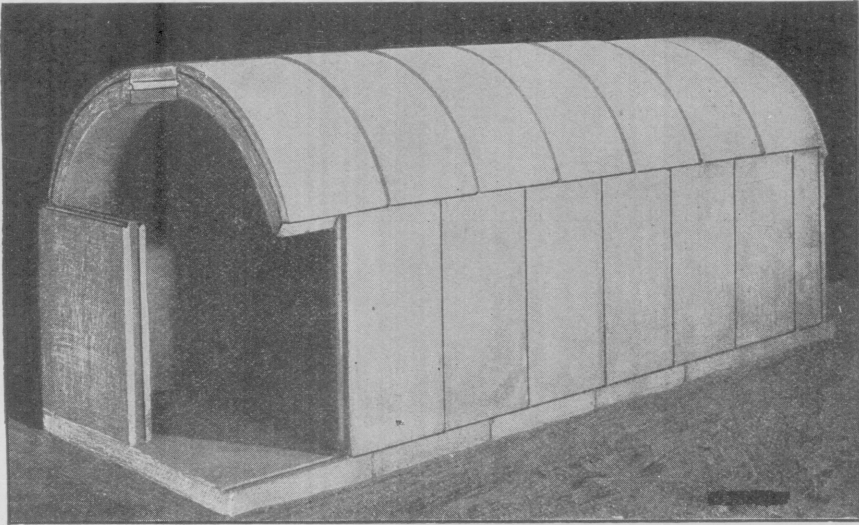


Fig. 65.—Concrete Burial Vault.

COEFFICIENT OF EXPANSION OF CONCRETE.

† From 1899 to 1901, Prof. Wm. D. Pence, of the Purdue University, Lafayette, Ind., with several of his students, carried on a series of tests to determine the coefficient of expansion for concrete. It was planned with special reference to the use of steel with concrete. The composition of the concrete was based upon the specifications of Mr. Edwin Thacher, M. Am. Soc. C. E., for a concrete for use in concrete steel construction: namely, 1 part cement, 2 parts sand and 4 parts crushed stone that will pass through a $1\frac{1}{4}$ inch ring. Lehigh Portland cement was used the first year and Medusa Portland the second. In the first series of tests Bedford oolitic limestone was used and in the second, Kankakee, Illinois, limestone was used. A bar of unbroken limestone was also tested in the second series.

"In the plan finally adopted a standard bar of steel or copper with known coefficient of expansion was subjected to identical changes of temperature with the test bar of concrete, and the difference of expansion of the two bars was determined by the principle of the 'optical lever.' This difference in length, reduced to a unit of length and temperature, gave a correction to be applied to the known coefficient of the metal bar."

† "Eng. Record, Feb'y. 22, 1902."

The results obtained were as follows:

Coefficient of expansion of gravel concrete, 0.0000054 per degree F.

Coefficient of expansion of broken stone concrete, 0.0000055 per degree F.

Coefficient of expansion of limestone bar, 0.0000056 per degree F.

The coefficient for concrete may be conveniently remembered as "five zeros fifty-five."

As the coefficient for steel is, closely, 0.0000060, the variation between steel and concrete is not sufficient to seriously affect their use in combination.

COST OF CONCRETE.

There are so many conditions, local and general, that enter into the cost of concrete, that but brief space will be taken up here to give a few instances of the actual cost of concrete for various purposes and in widely different localities. The prices of labor and material and the ease or difficulty of access to material and the work to be done, largely govern the cost of concrete.

TABLE No. 20.
Cost of Concrete—Using Portland Cement.

Date.	Location.	Class of Work.	Proportions.	Cost per cubic yard.	Remarks.
1880-85	Newhaven, Eng.	Breakwater	1-7	\$5.50	Laid in sacks.
1889	Buffalo, N. Y.	Breakwater		9.19	
1891	Buffalo, N. Y.	Breakwater		8.21	
1900-02	Buffalo, N. Y.	Breakwater	1-3 -4	5.65	
1900-02	Buffalo, N. Y.	Breakwater	1-3 -4	6.64	
1890-91	Toronto, Can.	Road Foundation.	1-2 -7½	4.83	Eng. News Feb. 17, '98. Gov't and contract work.
1895	Marquette, Mich.	Breakwater	1-2½-5	6.35	
1899	Marquette, Mich.	U. S. Breakwater		4.57	
1889	Buffalo, N. Y.	Harbor Work		8.75	
1893	Gr. Kanawha, W. Va. ...	River Improv'ment		7.25	
1897	Monongahela River.	Lock and Dam		11.00	Approx.
1898	Chicago, Ills.	Sidewalks.	1-2 -5	10.00	

TABLE No. 20—Concluded.

Date.	Location.	Class of Work.	Proportions.	Cost per cubic yard.	Remarks.
1903	Chicago, Ills.....	Sidewalks.....	1-2 -5	12.50	Approx.
1899	Columbus, Ohio.....	Levee	1-2½-5	5.75	Work by day labor.
1889	Columbus, Ohio.....	Dam.....		4.95	Average of ten bids.
1900	Chicago, Ills.....	C. & N. W. Ry.	1-3 -4½	4.81	Track Elevation.
1902	Chicago, Ills.....	L. S. & M. S. Ry..	1-3 -6	\$6.25	Retaining Wall.
1903	Peekskill, N. Y.....	Tunnel	1-2 -4	10.72	Lining of Ry. Tunnel.
1903	Columbus, Ohio.....	Road Foundation.	1-4 -8	4.35	
1904	Columbus, Ohio.....	Curb and Gutter..		17.00	Approx.

TABLE No. 21.

Cost of Concrete—Using Natural Cement.

Date.	Location.	Class of Work.	Proportions.	Cost per cubic yard.	Remarks.
1895	Marquette, Mich.....	Breakwater		3.64	Governm't River and Harbor Work.
1894	New York	Harbor.....		3.55	
1897	Rough River, Ky.....	River Impr'v'm'nt		7.50	
1897	Herr's Island, Allegheny River	River Impr'v'm'nt		3.59	
1897	Monongahela River....	River Impr'v'mn't		8.00	
1900	Chicago, Ills.....	C. & N. W. Track Elevation	1-2 -3½	2.40	Including Forms.
1902	Chicago, Ills.....	L. S. & M. S. Ry..	1-2 -4	4.00	Foundation of Wall.

The cost of massive concrete can be materially reduced in price if large irregular boulders or stones are imbedded in the concrete. It is possible to do this without in any way weakening the mass. If concrete cost \$6.00 per cubic yard and stone costing \$1.00 per cubic yard was imbedded in the concrete to the extent of say 40 per cent. of the mass, then one cubic yard of masonry would cost \$4.00, a saving of one-third the cost of the original concrete.

CHAPTER IV.

THE USES OF CEMENT IN REINFORCED CONCRETE.

"Reinforced concrete," "Armored concrete," or "Steel concrete" as it is variously called, is the structure resulting from the use of concrete with iron or steel ribs or "bones" running through the concrete mass.

EARLY USE OF REINFORCED CONCRETE.

Condensed extracts from a discussion upon Steel Concrete Construction by Mr. A. L. Johnson, Assoc. M. Am. Soc. C. E., printed in the Proceedings of the American Society of Civil Engineers, follows. He gives to Mr. W. E. Ward the credit of having first used steel reinforced concrete in a scientific manner in a building which he erected in Port Chester, N. Y., in 1875. Mr. Ward constructed a building in which "not only all the external and internal walls, cornices and towers were constructed of beton (the word concrete was not then in use), but all the beams and roofs were exclusively made of beton reinforced with light-iron beams and rods."

"Francois Coignet of Paris, in 1869, took out patents on a combination of beton and iron rods, but he had no conception of the proper method of using the materials."

Monier built his first wire and beton flower pots in 1876, but the manner in which he combined the two materials showed that he did not understand the principles of reinforced concrete. He placed the wire webbing in the neutral axis of the slab; while it answered his purpose, it would be disastrous to attempt such construction upon beams or in bridges.

Thaddeus Hyatt, of England, began experiments upon reinforced concrete in 1876, the result of which he published in 1877.

It is probable that the first approximately correct formulas for reinforced concrete were derived by Julius Mandl in Germany, and Prof. J. B. Johnson in this country at about the same time.

L. A. Saunders, engineer for Monier construction, in Germany, published an extensive treatise upon the subject. In 1899 M. Considere, Ingenieur en Chef des Ponts et Chaussées. Paris, published a long discussion upon Ciment-armé. "His studies embraced the following points:

Geometrical and algebraic determinations of the moment of resistance of armed pieces, influence of the quality of the concrete and of the armatures, the most economical percentage of metal, effect of bad workmanship, value of the factor of safety, and the utility of symmetrical armatures." In more recent years Edwin Thacher has published from time to time the results of a careful mathematical investigation of the theory.

RECENT USE OF REINFORCED CONCRETE.

During the last four or five years many different systems have been developed, few of which have introduced any radical ideas into reinforced concrete construction.

Concrete has great compressive strength, but lacks reliable, uniform tensile strength. Engineers have sought to take advantage of the strength of concrete in compression for all classes of construction, but to do so they must insert some material to supply the much needed tensile strength, hence they have imbedded steel and iron bars of various sizes and shapes, in the various positions in the concrete mass where they conceive the tensile strains will occur. Tests have proved conclusively that greatly added strength has been given to such structures.

Professor W. K. Hatt,* Purdue University, Lafayette, Ind., has carried on a series of tests with his senior students which very clearly show the effect of reinforcing concrete beams. Concrete beams 8 by 8 inches square were tested in lengths of 80 inches between supports. The several beams were reinforced by $\frac{5}{8}$ and $\frac{3}{4}$ inch iron bars placed 1 and 2 inches from the lower face of the beam. The majority of the tests were made upon concrete composed of 1 part cement, 2 parts sand and 4 parts broken stone. A few tests were made upon cinder concrete and some with gravel concrete. The variables tested were age, per cent. of steel, position of steel and material.

One per cent. of reinforcement placed 1 inch from the bottom increased the strength of the plain concrete beams from 2,200 to 7,400 pounds, and increased the flexibility of the beam from a center deflection of 0.01 inch to 0.14 inch.

Two per cent. of reinforcement increased the strength from 7,200 to 10,000 pounds with only a slight increase in the flexibility. Raising the 1 per cent. of metal 2 inches from the bottom face decreased the strength from 7,200 to 5,000 pounds, with a slight decrease in flexibility.

"A cinder concrete and a stone concrete beam each reinforced with 2 per cent. of metal, 1 inch from the bottom face, had comparative strengths of 5,000 and 10,000 pounds, respectively, and a comparative flexibility of 0.26 and 0.16 inch, respectively. In case of plain cinders and stone concrete beams, the comparative strength was 600 and 1,800 pounds, and

**Eng. News*, July 17, 1902.

the flexibility was 0.023 and 0.016 inch, respectively. "It thus appears that reinforcing a beam with even 1 per cent. of steel gives it ten times its former flexibility and more than three times its former strength."

In plain foundations or heavy walls where concrete is only used in compression, and no transverse or tensile strains are brought upon the structure, there is no need for reinforcing concrete, for it has such great resistance to compression that it is as strong as can be desired for such work.

It is in beams, floors, light walls, roofs, bridges, arches, and a thousand other places where it is desirable to use concrete because of its many good qualities, but where it is placed in tension, that reinforcement becomes necessary. The qualities for which concrete are sought are, non-corrosion in moist places, non-rotting under any condition, resistance to fire, resistance to weathering, deadening of sound, ease of construction, especially by unskilled labor when directed by a few competent skilled men, cheapness compared with other stone of equal appearance, and its durability.

There are nearly as many systems of steel reinforced concrete as there are men who have attempted that kind of construction. The general theory is the same in each system, namely, that all transverse or lateral strains affect the material the same as such strains affect a beam; that is, by placing the fibres or material on the side from which the force is acting under compression and on the opposite side under tension.

As the concrete is an exceptionally good material for compression it needs no reinforcing upon the compression side, but as it is a poor material for tension, metal tension members are inserted upon the tension side. The systems fall into three classes, those that use expanded metal, those that use wire mesh and those that use iron or steel bars in some one of the various forms. Of the latter class, nearly every conceivable shaped bar is used—flat, round, square, twisted and special rolled shapes.

DANGERS FROM CORROSION.

One of the questions that the advocate of reinforced concrete must meet satisfactorily is, "Will your iron or steel members remain safe from corrosion and consequent weakening for an indefinitely extended time under all conditions?" There seems to be little doubt among cement users that when neat cement mortar or a sand mortar rich in cement is used there will be no danger from rust, but when cinders or open material or lean concrete is used they fear there will be corrosion. Stone, Carpenter and Willson, architects of Providence, R. I., are quoted as having inspected a five story steel skeleton building which was torn down after five years' service. The outside columns were surrounded with brick, the interior columns protected with wire lathing and hard plaster. The floors were of expanded metal and cinder concrete. Before destruction,

the floors were tested to 900 pounds per square foot. The general appearance of the columns was as good as when put in place. The expanded metal which was protected by cinder concrete showed a little rust in a few places, but not enough to give any apprehension. In fact, they said it appeared to have ceased rusting long ago.

Pabst Hotel, New York.—The Pabst Hotel, at the corner of Broadway and 42nd street, N. Y., was built in 1898 and torn down in 1903. The metal enclosed in concrete and terra cotta showed some rust, about as much as would occur while the concrete was thoroughly using all the water within it. This was a cinder concrete and quite porous.

World's Fair Specimen.—The writer, who was engaged at the Exposition Grounds throughout the building and operation of the World's Columbian Exposition at Chicago, saw the construction in 1892 of the cement exhibit of the Alsen Portland Cement Company. One portion of their exhibit was a concrete pedestal upon which were two large concrete figures, one of which held aloft a banner bearing the Alsen's advertisement. The writer visited Jackson Park in the summer of 1902 just as the final destruction of the statue occurred. It had long been broken down, but was then being broken into smaller pieces to act as filling along the embankment of a lakelet. While breaking up the head of this figure, a screw used as a holding pin by the artist who made the statue was brought to view. It was in excellent condition; a large portion of the surface came out of the concrete as bright and untarnished as the day it went in. A small part of the threaded portion which had not been intimately in contact with the cement showed a coating of rust; about as much as would have occurred if the screw had been wet and lain exposed for two or three days. This screw had been in service ten years, and for several years the head of the figure in which the screw was imbedded had been lying in the marshy sand at the south end of Jackson Park. A longer test would not have proven more conclusively that dense concrete protects steel against corrosion.

Norton's Experiments.—Prof. C. H. Norton, engineer of the Insurance Engineering Experiment Station, Boston, made a series of tests with steel and iron imbedded in cement, concrete and cinder concrete to determine the effect of the different classes of concrete upon the metals as to danger of rusting. Two brands of cement were used—neat, and with sand, stone and cinders. Concrete bricks 3 inches by 3 inches by 8 inches in dimensions with three specimens of steel in each, a rod of mild steel 6 inches long and $\frac{1}{4}$ inch diameter, a bar of soft sheet steel 6 inches by 1 inch by 1-32 inch, and a strip of expanded metal 6 inches by 1 inch in size respectively were used in each brick. He subjected these bricks to different conditions as follows: Some were subjected to steam, air and carbonic acid, some to air and steam, some to air and carbonic acid and one-fourth

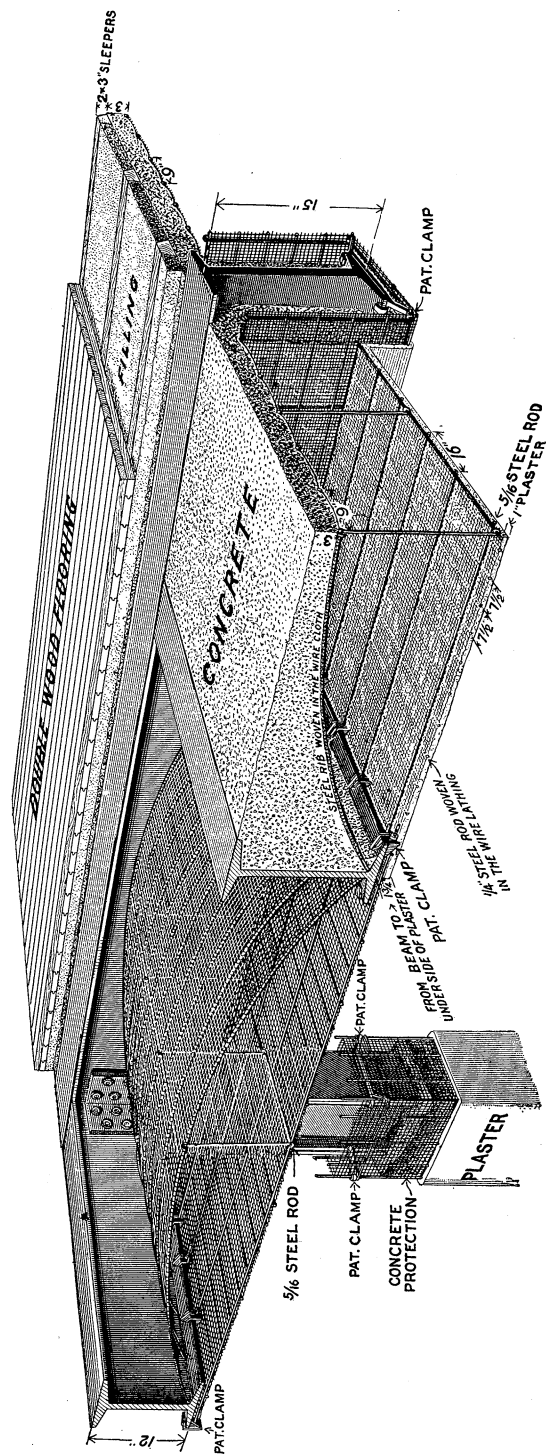


Fig. 66.—Roebling System A Arch Construction.

of the number stood in the air of the room. At the end of twenty-one days all were cut open. Unprotected steel subjected to similar tests was badly corroded. In the concretes wherever a crack or a void occurred the steel was more or less corroded. In neat cement no corrosion showed. Prof. Norton's conclusions are:

- 1st. Neat cement thoroughly prevents rust.
- 2nd. Concretes should be dense and without voids and mixed quite wet to prevent rusting the metal.
- 3rd. Corrosion found in cinder concrete is mainly due to iron rust in the cinders and not to the sulphur.
- 4th. Cinder concrete free from voids and well rammed wet is nearly as effective as stone concrete.
- 5th. It is of the utmost importance that the steel should be clean when it is imbedded.

THE ADHESION OF CONCRETE TO METAL.

The necessity of taking additional precaution for preventing the separation of the metal and the concrete when placed under great strain is viewed quite differently by the various experts in reinforced concrete construction. Prof. Bauschinger of Germany determined by a series of tests that steel or iron and cement adhere to the extent of 625 pounds per square inch of surface. Messrs. Krumm and Senter, civil engineering graduates of the Ohio State University, found by a series of tests that one inch iron rods set 12 inches into neat cement mortar after 22 weeks, required a pull of 530 pounds per square inch of imbedded surface to draw them out. In a mortar of 1 cement to 1 sand, 12 to 16 weeks of age, it required from 723 to 772 pounds per square inch of adhering surface to extract the rods. Assuming the tensile strength of iron or steel at 60,000 pounds per square inch and the adhesion of cement mortar to steel at 625 pounds per square inch, round steel bars would need to be set but 24 diameters depth in the mortar to require the breaking limit of the bar in order to pull them from the cement.

On the other hand, experts say that as soon as sufficient force has been applied to elongate the metal rod appreciably, the rod has then become lessened in cross sectional area, and as concrete is not elastic to any measurable extent such decreased rod area means a breaking away from the adhesion and consequently a decreasing reinforcement to the concrete.

If, however, the bar is completely imbedded in the concrete and is gripped over each particle of its superficial area by a grasp equal to 625 pounds per square inch, it must take a very much greater stress to begin the process of elongation. Some of the most successful armored concrete builders ignore any additional mechanical means of uniting metal and concrete. Among the number may be named Monier, Hennebique, Weber and others. On the other hand, Ransome, Thacher, Roebing and others provide special means to cause a more perfect union between the two materials.

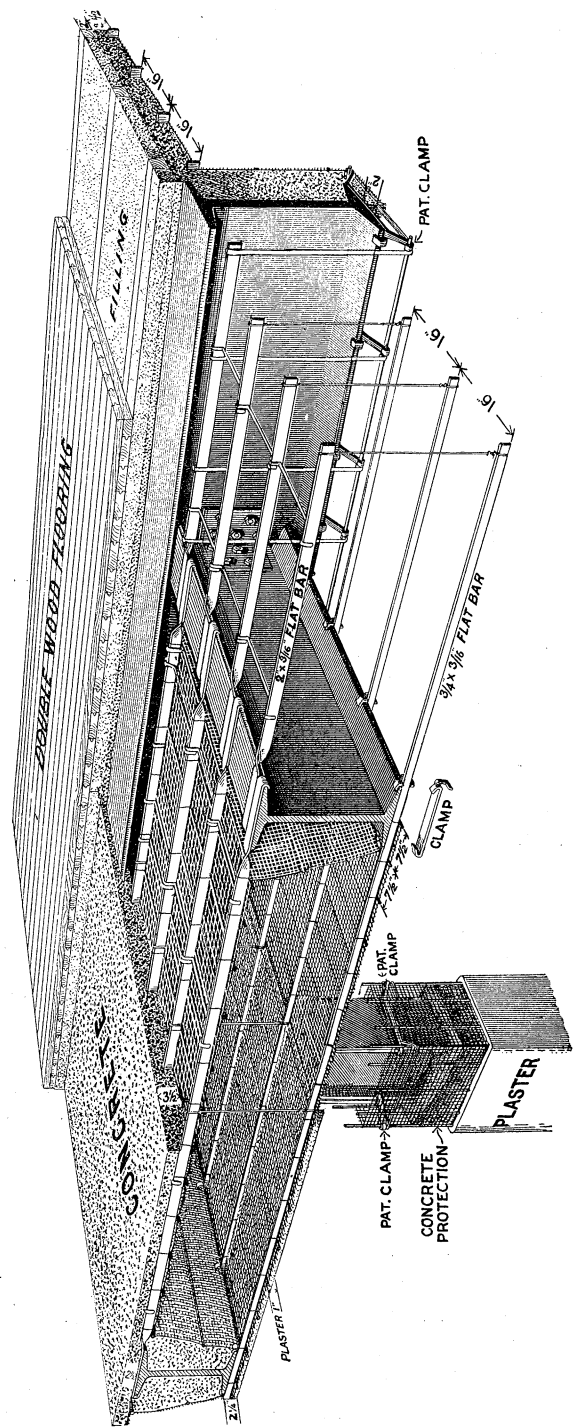


Fig. 67.—Roebbing System B Arch Construction.

DESCRIPTION OF VARIOUS SYSTEMS OF REINFORCED CONCRETE.

But brief descriptions can be given here of the more important systems with their essential differences.

Monier System—In the words of Mr. E. Lee Heidenreich, C. E., the agent representing that system in this country, "The Monier construction consists of two materials, wrought iron or steel, and mortar, consisting of cement and sand, or cement, sand and broken stone. The iron or steel is either in the form of rods or wires, and are designated as carrying rods and distributing rods. The first ones being quite heavy are calculated to take most of the tensile strain of the construction; the distributing rods being lighter and serving the purpose merely to distribute evenly the load over the carrying rods. The two systems of rods are applied like a netting with meshes, varying according to the requirements of the construction, from say two inches to ten inches square. In most cases the distributing rods are placed at a distance apart equal to about twice that of the carrying rods."

The two systems of rods are wired together and this network of wires or rods is placed in the forms prepared for the concrete at about one-sixth of the thickness of the concrete plate from the side which is exposed to tension and held there by wedges until the concrete is thoroughly incorporated around the rods and fills the molds.

This system is applicable to any form of construction possible, the increase in the mesh and the size of the rod covering all the ranges of construction from a flower pot to a railway bridge. It is particularly adapted for the construction of the smaller sizes of sewer, irrigation and water supply pipes.

Roebling's System.—The Roebling system "A" consists of woven wire mesh stiffened by steel rods, which is sprung in between floor beams or girders in an arched form. Upon this arch, concrete is deposited and allowed to harden. For ceilings, a system of rods is attached to the lower flanges of the floor beams by patent clamps which offset the bars below the beams for one-half inch or more. Under these rods and securely fastened to them by wiring, is placed the Roebling woven wire lathing, reinforced with one-fourth inch stiffening rods. A coating of one inch of plaster composed of cement or "hard plaster" is troweled upon the underside, thus producing their fire proof construction. This system is especially fitted for fire proofing floors, beams, columns, etc. Figure 66 shows it in detail. In their system "B," flat iron bars, set on edge, are clamped from beam to beam, both on top and bottom, and the wire meshing fastened to the bars. A $3\frac{1}{2}$ inch layer of concrete is then put above the upper wiring and 1 inch of plaster below the lower wire mesh. In this method the floor beams are encased on all sides to prevent fire reaching them. Figure 67 shows this system.

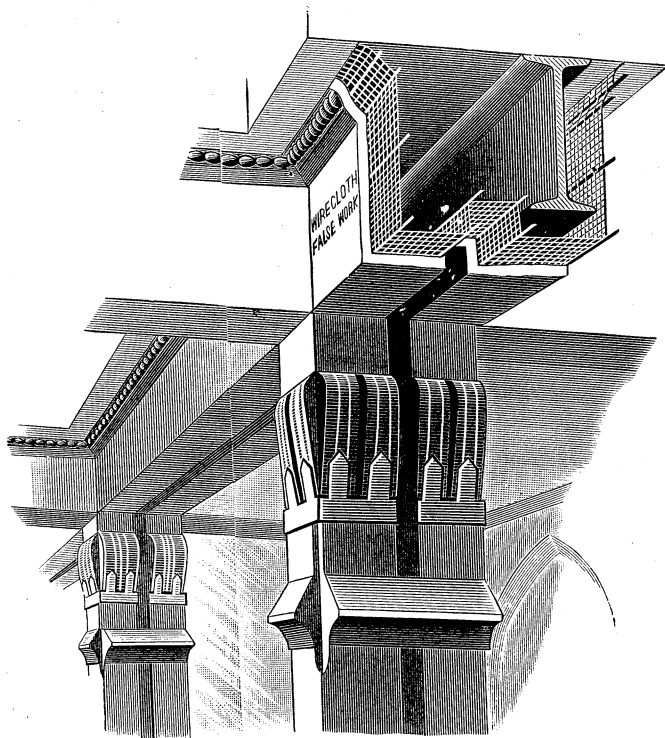


Fig. 68.—False Work for Giving Massive Effect in Plaster.

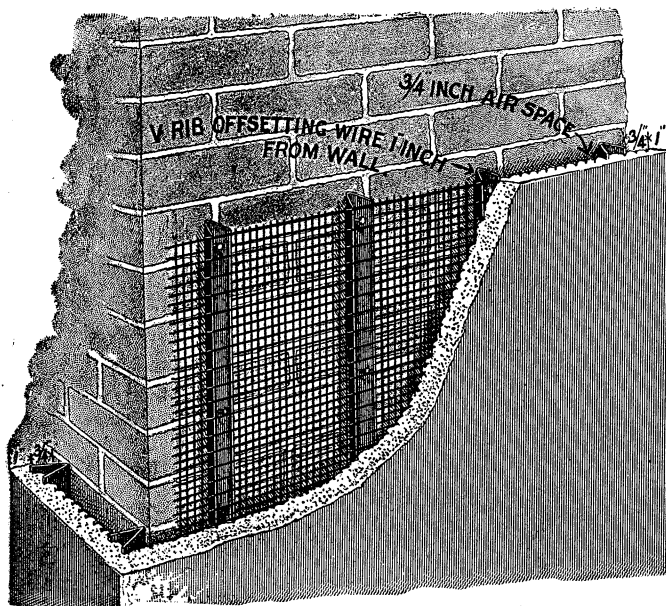


Fig. 69.—Exterior Wall Showing Metal Furring.

In protecting steel columns or girders, the wire lathing is furred out 2 inches or more from the member by specially designed metal clamps and bars, the space inside is then filled with cinder concrete before the outside is plastered.

The concrete used is 1 part Portland cement, $2\frac{1}{2}$ of sand and 6 parts cinder. It is never rammed solidly, but allowed to set in porous form. It dries out quickly, is light, and the porosity prevents the fracturing of the concrete under sudden changes in temperature. Concrete under these conditions weighs about 80 pounds per cubic foot.

Strength of Roebling Arch.—To test the strength of the Roebling arch system, the New York Building Department in 1896 made a severe test upon a 4 foot arch. It was first subjected to a five hour fire test at temperatures ranging from $2,000^{\circ}$ to $2,350^{\circ}$ F. and then cooled by a stream of water from a fire engine. A section of the arch 4 feet long was then cut free from the remainder of the arch and the middle $2\frac{1}{2}$ feet of this section was loaded with a load of 41,000 pounds, or a load of 2,556 pounds per square foot over the entire arch, which safely withstood the test. The heat of the fire test was sufficient to fuse the brick side walls and to cause the surface of the brick to run down the wall like molten metal. Figures 68 and 69 illustrate other methods of using the system.

Expanded Metal System.—Expanded metal consists in sheet steel slit in regular lines and then the strips forced apart forming diamond shaped meshes. Sheets of this metal are then laid over the girders with ends lapping and the concrete lightly tamped in around the metal. The metal is sometimes sprung in between beams as is done in the Roebling system. Expanded metal makes a very strong floor as is shown by a test made upon a floor slab for the Larkin Soap Co. of Buffalo, N. Y. A 4 foot 10 inch span of floor 3 inches thick and 13 feet 10 inches long was subjected to a uniformly distributed load of 2,333 pounds per square foot without indicating weakness. The load was then changed to a concentrated load 12 inches wide in the center of the panel extending for full panel length. The floor panel broke when the total load amounted to 4,855 pounds per square foot. Expanded metal is particularly adapted to thin partitions where the metal can be tacked to each side of metal or wooden studding and cement mortar plastered upon both sides forming a very durable solid wall of minimum thickness.

Melan System.—The Melan system consists of concrete reinforced with steel I-beams, bent to conform to the tension surface of the structure. In this country it has been principally used in bridges. The I-beams vary in size to suit the requirements of the span and load. They are set at intervals of two or three feet apart laterally, and the lower flange is kept about three or four inches from the bottom face of the arch. As the concrete varies in depth from the crown to the haunch of

the arch, it follows, that a single I-beam gives no reinforcement to the top surface of the concrete at the haunch. It was to avoid this defect and

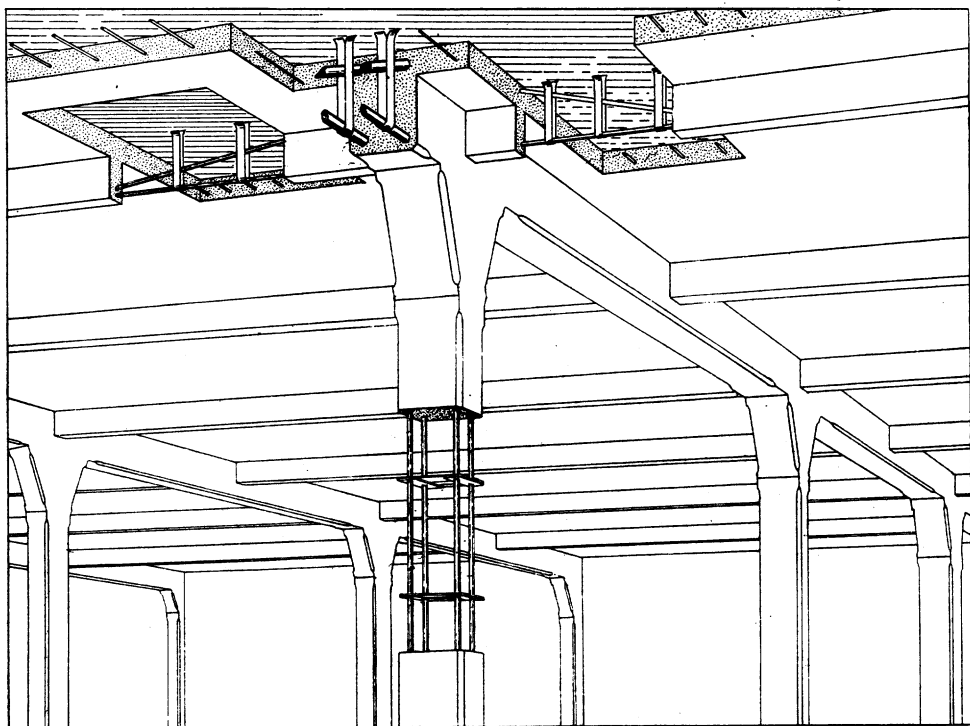


Fig. 70.—Floor and Post Construction, Hennebique System.

to secure a simpler, more conveniently obtained form of steel that Thacher introduced his system described below.

Thacher System.—The Thacher system of reinforced concrete is particularly designed for bridge construction. It consists of pairs of flat iron or steel bars laid near the upper and lower surfaces of the arch, spliced and riveted so as to be continuous from one abutment or pier to the next. These two members are tied together with vertical iron rods spaced two or three feet apart. Large headed rivets are set in the bars at short intervals to give a better bond with the concrete. The pairs of bars are spaced about three feet apart laterally and not connected. These bars act as the flanges of a beam of which the web consists of the body of concrete. The advantages of this system are: The simplicity of the metal forms, the convenience in obtaining, shipping and handling, and the ability to place the metal nearest to the maximum tensile straining points. It gives greater moment of inertia and consequently greater strength for the same amount of metal than does the original system from which it sprang; namely, the Melan I-beam system. The special

Thacher rolled bar, (a later design) does not have the first two advantages named. Illustrations of Thacher's original method of reinforcement will be given later under the head of bridges.

Hennebique System.—The Hennebique system gives the effect of a trussed concrete beam by the use of two sets of round iron bars. One set is straight and laid near the lower edge of the beam, the other is bent upward at the ends, approaching the upper part of the beam. Besides these, vertical U-irons, or stirrups, are used to assist in resisting both shear and bending. Application of this system to columns and other forms of construction is quite as simple. In the column four or more round iron rods are used, bound together at frequent intervals with iron plates through which they pass, or they are bound together by being heavily wired. These rods give the tensile resistance required while the concrete gives the compressive resistance and rigidity to the structure. The Hennebique system has been used in every form of construction in which armored concrete can be used—tanks, stairways, floors, walls, bridges, piles, etc. Figures 70 and 71 show its detail for floors and beams.

Contrary, also, to usual practice, Hennebique prefers the steel or iron to be "covered with rust to facilitate the foundation of an extra hard coat of ferro-concrete, which prevents the penetration of moisture and air to the metal."

Ransome System.—The Ransome construction "consists in the use of iron bars, cold twisted, so as to form a continuous bond with the concrete, in which they are permanently imbedded."

"The basis of the system is the method of introducing iron with concrete in such a manner as to give to the concrete beam or girder the power to resist tensile stresses, as if the beam were of a fibrous or homogeneous material, like iron or wood. In such a construction it is essential: *First*, that the iron and the concrete be so united as to enable each to act immediately with the other in resisting stresses. *Second*, that the bond between the two should be continuous and equal from one end of the beam to the other. *Third*, that the elastic limit of elongation of the two should be made as nearly equal as possible."

Ransome claims for his system of cold twisted bars, increased elastic limit, decreased elongation under strain, the detection of all serious imperfections in the iron before it is put into use, and a more secure union of the metal and concrete. He does not attempt the trussing effect, but allows the concrete to form its own truss, depending upon the iron to supply the tension member. It costs about one dollar per ton to twist the iron so that if all is gained that is claimed, the twisting certainly pays. In floor or surface construction, auxiliary bars are used running at right angles to the main system of bars.

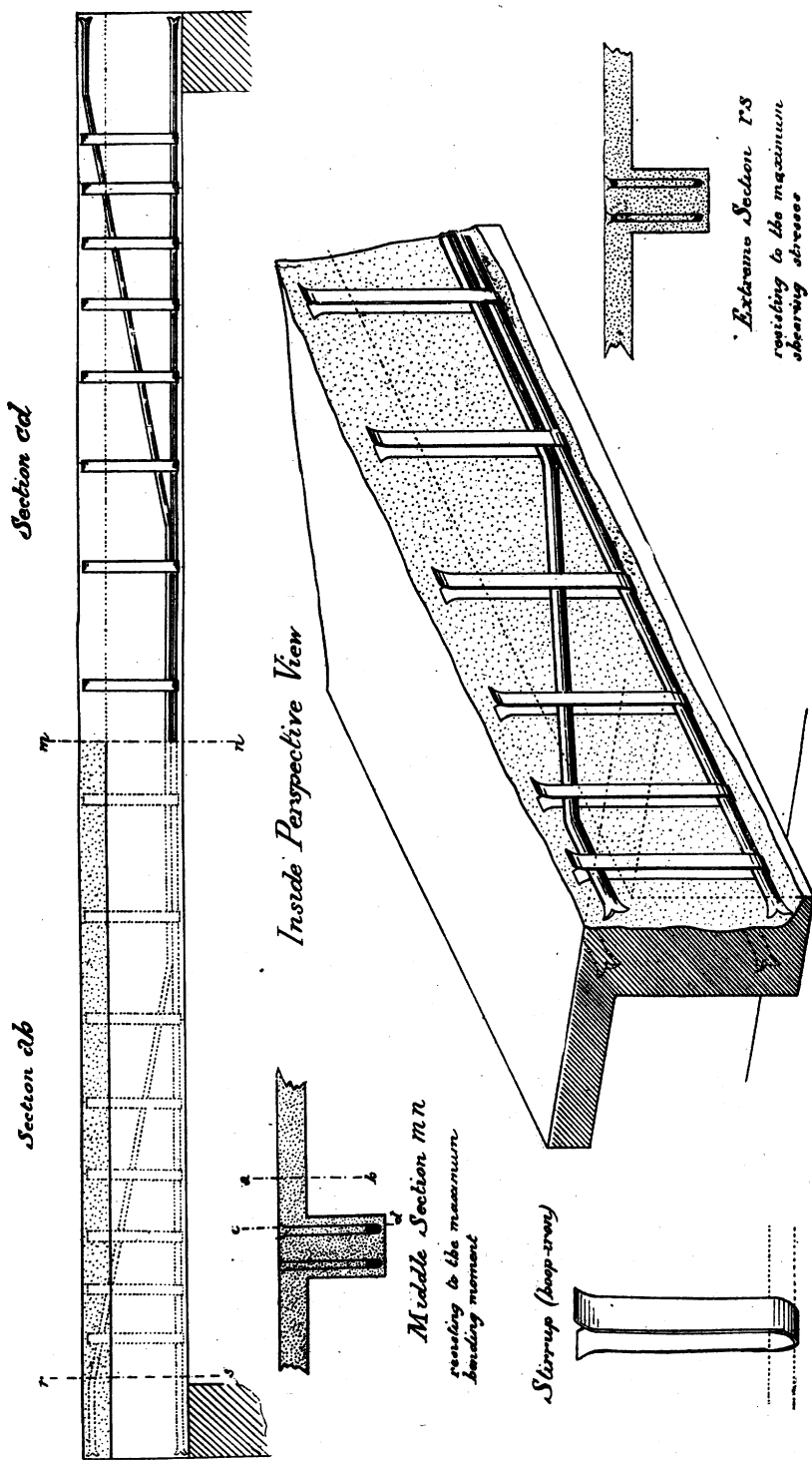


Fig. 71.—Details of Construction, Hennebique System.

Weber System.—In the Weber system steel T bars are used for reinforcing the concrete, the advantage being that the T form gives a much greater surface contact for union with the concrete, than do round or square bars having the same cross-section. The T shape also resists a much greater bending force for equal amounts of metal. This being one of the standard shapes is readily obtained at reasonable prices. Longitudinal and lateral bars are easily clamped together, back to back, by specially designed clamps which work very simply so that the reinforcing skeleton is quickly put in place. Figure 72 shows the details of this system.

Kahn's System.—This is one of the later developed systems, and seems to have some excellent features to commend it to engineers. In the first place it is a form which can be easily rolled and easily cut and pressed into the shape desired. In the second place it seems to offer a reasonable solution of furnishing the tension member at every position where it is most needed. It amounts to the same reinforcement furnished by the Hennebique system, and does it with a much simpler piece of metal to place in position. Its form readily fits it for a great variety of structural purposes. It would seem to be especially adapted for floors, beams and walls. Figure 73 shows the shape of the metal member.

Columbian System.—The Columbian system is another method of using bars and strives by the shape of the bar used to gain in rigidity and in binding union with the concrete. The bar is ribbed, having a central web from which three to six ribs running longitudinally of the bar set out at right angles on each side. As it is an unusual form, it can only be obtained at the few rolling mills which may install the necessary rolls. Being an unusual form it will probably cost more than the simpler and customary forms. The claims made for it are: The greater surface presented for adhesion of concrete, the rigidity of the metal piece itself, and the additional rigidity given when supported by concrete firmly imbedded between the ribs or flanges. Figure 74 shows a section of the metal.

Cumming's System.—This system employs round iron rods in place of the Kahn system of flat ribbed bars. These rods are bent into sets of long, slim parallelograms. Each parallelogram is sufficiently narrower than the one preceding it to lay within it and is considerably shorter. A short portion of the ends of each parallelogram is then bent up to make an angle with the horizontal of about 45 degrees. This nest of bent parallelograms is then laid into the form with its lower edges about two inches from the lower surface of the beam. The concrete is then tamped into place. The result accomplished is the same as with the Kahn reinforcement, but the accomplishment is not so simply and easily attained. Figure 75 illustrates the metal forms.

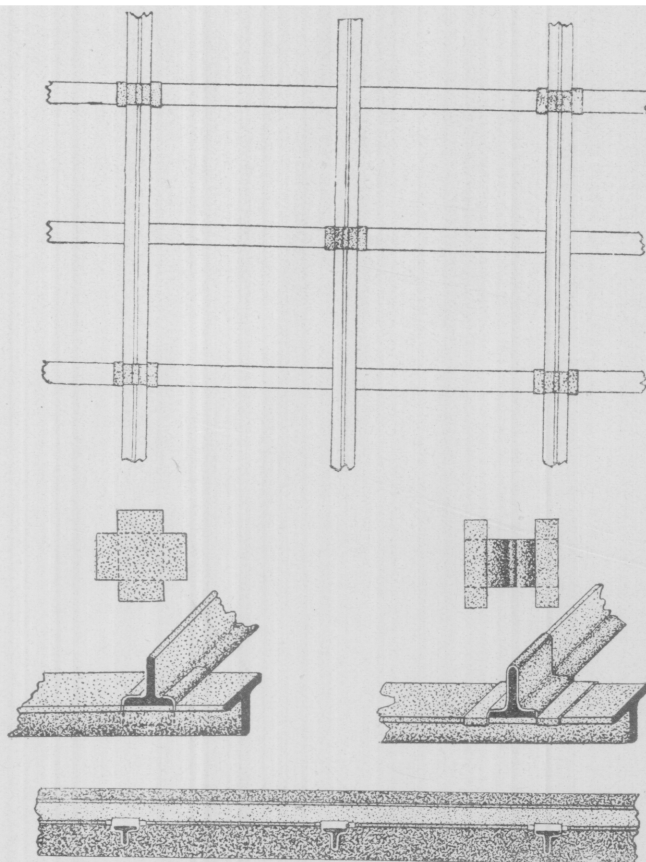


Fig. 72.—Details of Construction, Weber System.

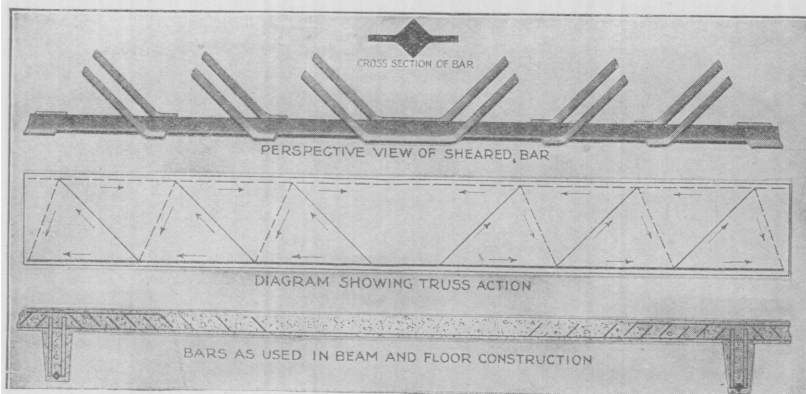


Fig. 73.—The Kahn System of Metal Reinforcement.

DeMan's System.—DeMan uses a flat steel bar with quarter twists put into the bar, alternately to the right and left, at intervals of two to four inches, according to the size and depth of bar. These bars are shaped so as to hook over the I-beams and are straight longitudinally except for the twists. This system is designed principally for floors. A specially designed concrete floor block is made which is cast at central manufacturing plants and shipped to the building, ready to slip into place between the floor girders. This block is as deep or deeper than the I-beam and rests upon the lower flange. The DeMan steel bars being special shapes are not as readily obtained as standard forms and consequently are objectionable for that reason.

Luten's System.—Luten's system pertains more especially to bridges and culverts and is particularly an application of any system of reinforced concrete, to a certain method of building rigid structures. Instead of allowing the thrust of the arches to be taken up by abutments, and embankments, a steel concrete tie is inserted from the base ends of the arches, making a monolithic complete structure, capable of sustaining all the varying stresses within itself. The advantages secured are: Prevention from arch rupture due to settlement, the possibility of flatter arches, a more rigid resistance to action of floods and possibly a slightly less amount of material necessary in construction. Figures 76 and 77 show a section and view of bridges illustrating this method.

It will be seen from the preceding discussion and descriptions that reinforced concrete gains its marked pre-eminence over plain concrete in such structures as bridges, girders, beams, floors, roofs, thin walls, chimneys, piles, etc., structures where great tensile strains enter into portions of the building. Again, in localities where both stone and gravel are scarce, reinforced concrete, because of the reduced amount of material required, is very economical. In describing the uses of reinforced concrete, but brief attention will be given to such structures as are commonly built with plain concrete, except, perhaps, to occasionally compare the results obtained by the two methods. The various methods of building beams and girders have been so well illustrated in describing the various systems of reinforcing, that they will not again be mentioned.

STEEL CONCRETE FOOTINGS.

The soil in Chicago is especially noted for its instability. This condition requires the highest engineering skill to be used in designing rigid, firm foundations for the "skyscrapers." The old form for foundations was of stone or immense blocks of concrete, taking up the room which should be given to basements and adding so much extra weight to the total load which the foundation soil had to sustain. To obviate these objections, the first combination of steel with concrete for heavy founda-

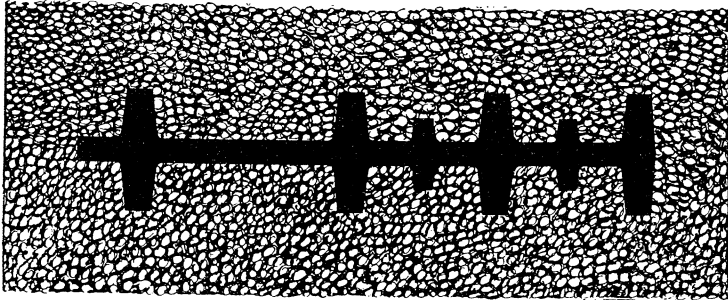


Fig. 74.—The Columbian System of Metal Reinforcement.

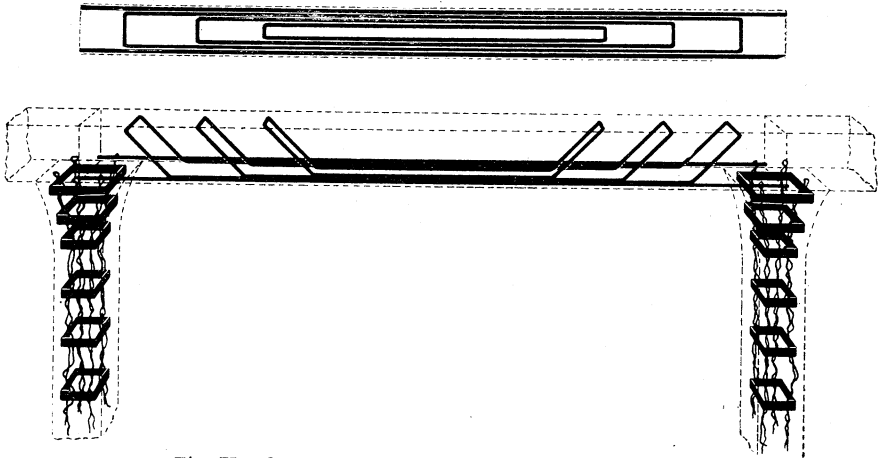


Fig. 75.—Cummings System of Metal Reinforcement.

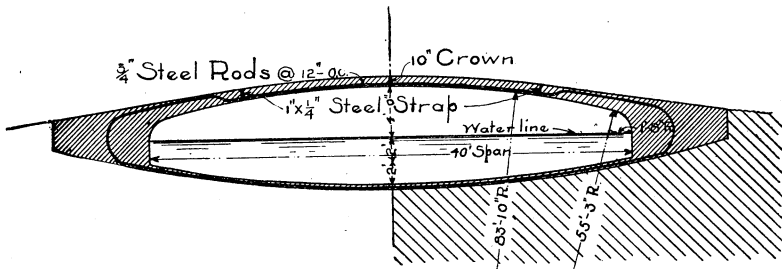


Fig. 76.—Section of a Bridge With Forty-Foot Span, Lafayette, Ind.
The Bed of the Stream is Paved With Concrete.

tions was designed. These foundations consisted of beds of concrete with grillages of steel rails or I-beams bedded in concrete, on top of them. Such foundations have long been successfully used there under the most trying conditions.

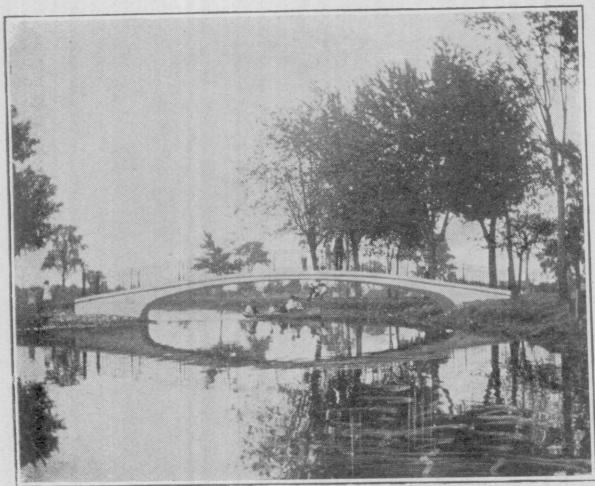


Fig. 77.—A Flat Elliptical Arch Bridge.

In order to compare the two forms, figures 78 and 79 are taken from an article by Mr. T. Corydon Purdy, published in *Engineering News*. Both foundations begin with a bed of concrete 18 inches thick and $16\frac{1}{2}$ feet square. Both were designed to carry a load of 800,000 pounds. The height of the steel-concrete foundation is 18 inches over the base, while the stone foundation is 7 feet. The weight of the steel concrete foundation is 103,000 pounds, and that of the stone foundation is 261,000 pounds. The reduction in weight is more than sufficient to allow an additional story to the building without extending the footings. The decreased depth of footings allows space for a basement. The steel concrete foundation can be erected in much shorter time. It is susceptible of development into cantilever form and therefore becomes particularly useful for sustaining separate walls along party lines. Thus steel concrete foundations save in basement space, in weight upon foundation soil, in time of construction, and in first cost.

The I-beam grillage, however, used a great deal of steel which it has since been discovered could be saved by using much smaller bars or rods imbedded in the concrete in grillage form. Figures 80 and 81 show another comparison which the St. Louis Expanded Metal Company make, and in which they claim that the first cost of construction saved by using bars is nearly as great as the saving in space.

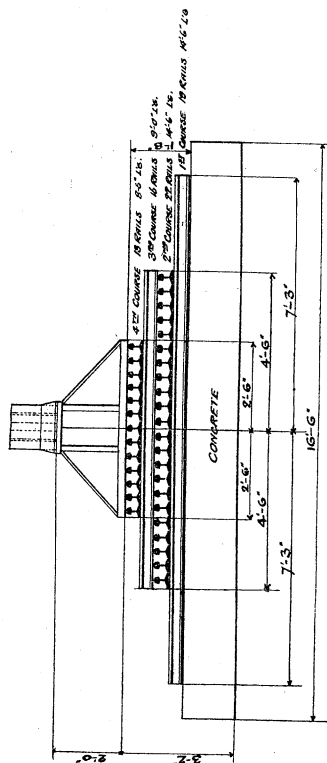


Fig. 78.—Steel Concrete Foundation.

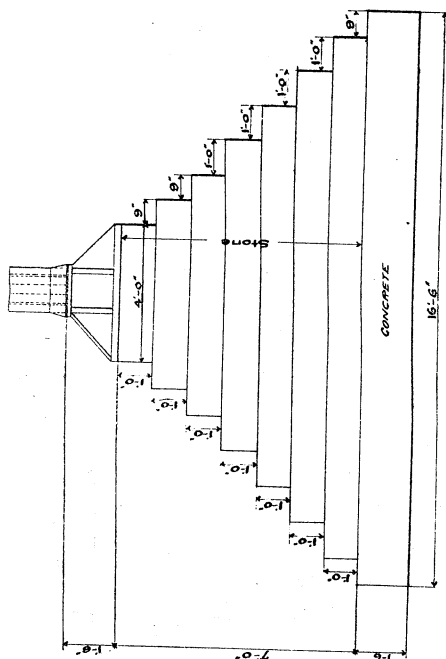


Fig. 79.—A Stone Foundation to Carry the Same Load as Provided for in Fig. 78.

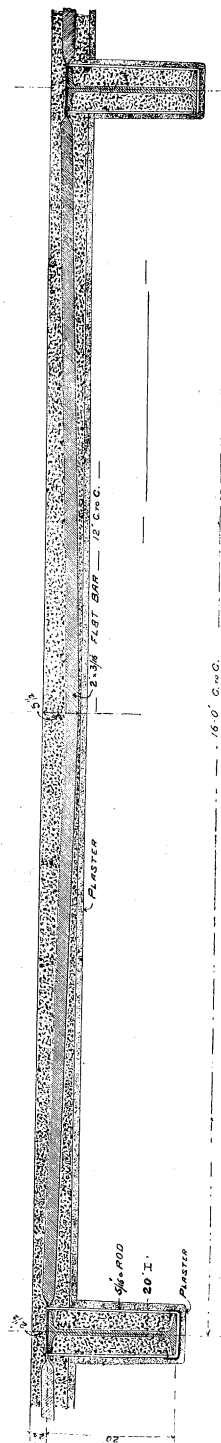


Fig. 82.—Steel Concrete Floor, After the Roebling System.

COST OF PLAIN CONCRETE FOOTINGS.

Excavation, 11½ cubic yards, at \$.50	\$ 5.75
Concrete, 205 cu. ft., at \$.20	41.00
Total cost	\$46.75

COST OF CORRUGATED BAR FOOTINGS.

Excavation, 7½ cu. yds., at \$.50.....	\$ 3.75
Concrete, 102 cu. ft., at \$.20	20.40
Corrugated bars, 382 lbs., at \$.03	11.46
Extra Column length, 85 lbs., at \$.03½.....	2.98
Total cost	\$38.59

A saving of nearly 17½ per cent. in cost. The percentage of saving increases rapidly as the size of the footings increase.

WALLS.

To have partition walls that are solid, fire proof, economical of space, and poor conductors of sound is one of the requisites of a modern office building. It is useless expense to construct any but ideal walls when so many good structural forms are available.

While visiting the Pacific Coast Borax Company's works, at Bayonne, N. J., in the summer of 1902, the writer was shown the partition walls which withstood the destructive fire that occurred in that building a few months before. The walls were of Ransome steel concrete three inches thick. To illustrate the strength of the wall the superintendent picked up a large wooden maul and swinging it at full arm's length, gave the wall repeated blows with all the force he could command. The wall vibrated slightly, but no other effect was produced.

FLOORS.

In all large cities, architects, owners, and building departments are striving to attain perfection in fire proof buildings. Attention is especially being directed toward construction that will confine fires to the rooms in which they begin. Fire proof walls should be accompanied with fire proof floors, stairways and elevator shafts. The old method of arching brick or massive concrete between steel I-beams is too cumbersome. Such floors are very heavy, adding to the weight which must be sustained by the floor beams, columns and foundations. They are not entirely satisfactory when it comes to severe fire tests, for the under sides of the steel I-beams are exposed to the heat of the fire and are soon warped out of shape, destroying the floor and allowing the fire to sweep upward through the entire building.

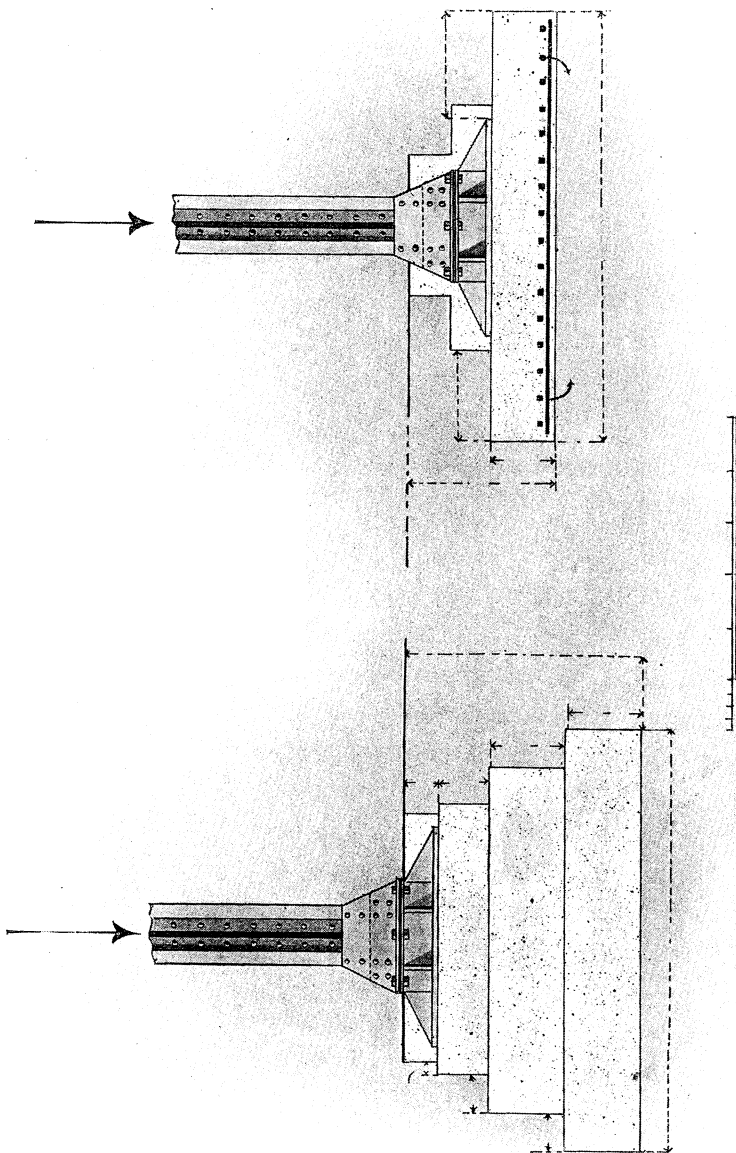


Fig. 80.—Plain Concrete Foundation.

Fig. 81.—Reinforced Concrete Foundation to Carry the Same Load as Fig. 80.

Steel concrete floors and beams were designed to meet this objection. Contractors have become bolder and bolder as experience and science have taught them the strength of this combination, until it is not unusual now to find four inch floors of steel concrete spanning 18 by 22 foot bays. These floors are made of excellent concrete having iron rods or bars imbedded in the lower third of the mass and supported upon steel concrete beams or girders. Figure 82 shows the section of such a floor.

"This type of flooring is similar in every way to the other System B floors (Roebbling's) except that the flat steel bars are bent or crooked downward 2 inches or more at the center of the span and imbedded in that position in the concrete. This type is particularly well adapted for floors of light capacity and where special conditions make it necessary to economize as much as possible in the structural steel. Where the distance between the steel members or supports is more than 9 or 10 feet, this form of flooring will be found more economical than any other. It may be employed to span directly from girder to girder, dispensing with the customary intermediate beams. Type 5 has been installed successfully in spans up to 22 feet. Under ordinary conditions, however, considering both the steel work and fire-proofing the most economical results will be obtained when the girders are spaced 14 to 16 feet apart. The weight of the concrete and imbedded steel bars as shown in the illustration is 43 pounds per square foot; plaster (two coats), 7 pounds."

English Practice in Floor Construction.—Mr. Frank Caws, who has had thirty-two years experience, gives the following rules for concrete floor construction, in an article written for the Journal of the Royal Institute of British Architects.

1. Obtain old cement.
2. Use good broken brick aggregate and not sand, body concrete to be 1 part cement and 4 parts brick and the surface to be 1 part cement and 3 parts crushed granite.
3. Use as a precaution, "Sheep-wire netting" as a base and steel bars of 1½ pounds per foot in weight spaced 3 feet apart.
4. Consider a slab 10 feet square by 4 inches thick capable of bearing 900 pounds per foot in weight including its own weight and reckon for every slab, more or less than 900 pounds per foot directly in proportion to the square of the thickness and inversely as the cube of its span. When the span is rectangular the minimum span is taken.
5. Avoid casting slabs in frosty weather.
6. Cast large areas at once, leave no partially cast slab over night.
7. Insist on strong centering—leave it up at least five weeks.

STAIRWAYS.

If stairways and elevator shafts are of wood then fire will be carried from floor to floor, so that these, too, are now constructed of steel con-

crete. Not only in business houses but also in the finest residences concrete stairways are used.

George W. Vanderbilt's fine residence on Fifth Avenue, in New York City, is just being erected with a fine double spiral stairway. These spiral stairways curving in opposite directions intersect midway between floors, then swinging apart again continue to curve to the upper floor. They are self supporting, without beams, girders or columns. They are of exceptionally light construction, the concrete spiral, being 64 inches wide and 4 inches thick, with side panels or vertical edges 4 inches thick and 14 inches high. Ransome twisted bars $\frac{1}{4}$ inch square are used,

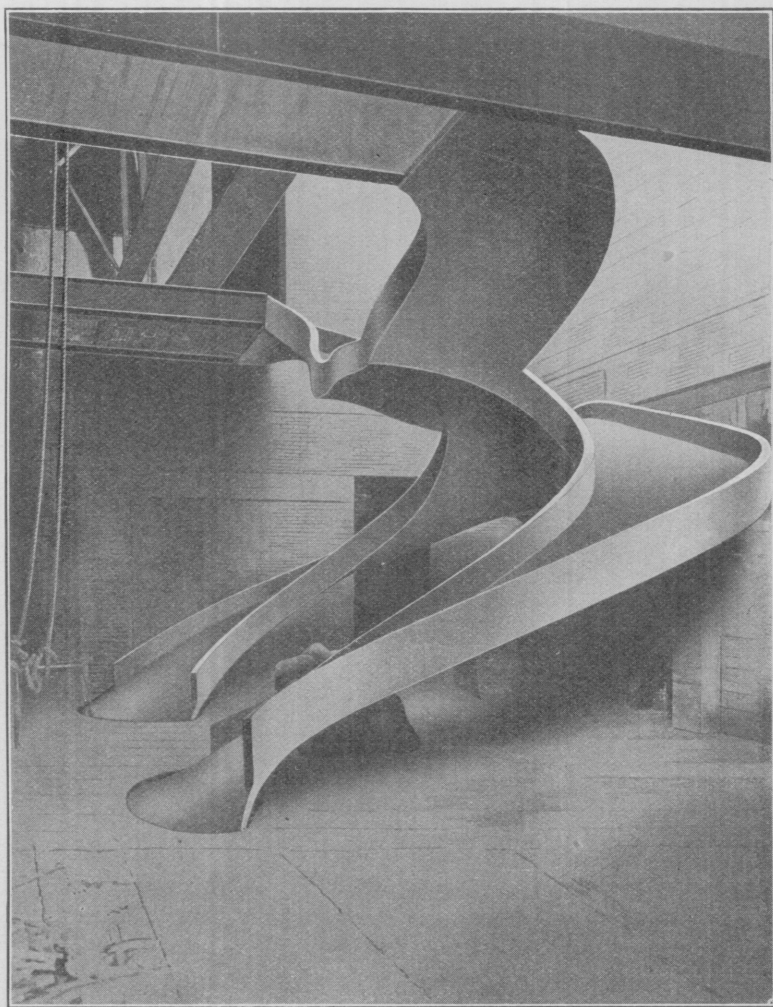


Fig. 83.—Steel Skeleton for Spiral Stairway, Geo. W. Vanderbilt's residence, New York.

mainly, for reinforcing material. The concrete used was mixed in the proportions of 1 part cement, $1\frac{1}{2}$ sand 3 parts of $\frac{3}{4}$ inch trap rock. Two weeks after the erection, the stairway bed was loaded with 3,300 pounds and showed no deflection. For a second test a 380 pound weight was dropped 11 feet upon the center of the floor bed without any perceptible effect. The wooden stair treads are to go upon this spiral sweep of concrete. The reinforcing rods were carefully bent to fit every curve and were in continuous lengths from the first floor to the intersection of the spirals, thence other rods from that point extend to and are bolted into one of the steel floor beams above.

In designing the house, it was found that all steel or other construction would have either required outside support or have been too heavy in appearance. This was the reason for adopting the light, graceful, steel-concrete work.

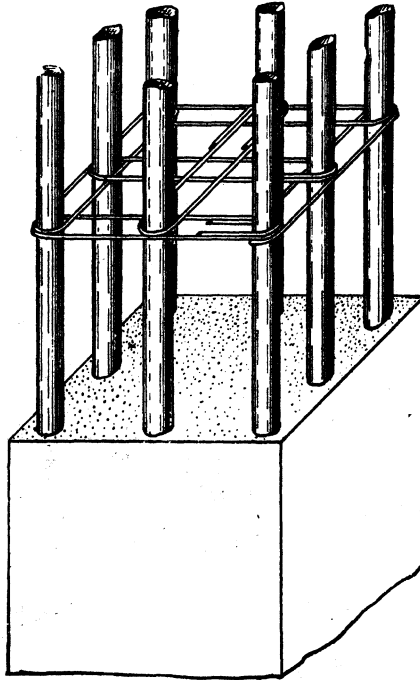


Fig. 84.—Section of Steel Concrete Column, Hennebique System.

COLUMNS AND PILLARS.

So many disastrous fires have occurred where iron columns have been used that architects have been seeking continuously for a remedy or a new material to replace the old.

Originally, fire proofing material was erected around the iron columns and this method is now much used. Both terra cotta forms and expanded metal, or wire lath with concrete are used for this purpose. Quite

a controversy has been aroused between the advocates of the two materials, in which the concrete people seem now to have slightly the advantage. But going beyond this use of a concrete veneer, the more advanced have omitted the large iron members and have substituted a concrete column with a few round or square steel bars placed vertically in it and have secured a column that no fire can warp or affect in any way.

Figure 84 shows the latter construction.

In the Christian Science Temple near Broad Street and Grant Avenue in Columbus, Ohio, the architect has saved the expense of stone and stone cutter's wages by making the porch pillars of concrete. Carpenters have built forms out of lumber. These were filled with concrete, and now symmetrical and inexpensive masonry pillars adorn the front of that concrete temple. The walls themselves are constructed of concrete blocks made upon the ground.

Figure 85 shows the unfinished front of this building and figure 86 is a more detailed view of the foot of the columns.

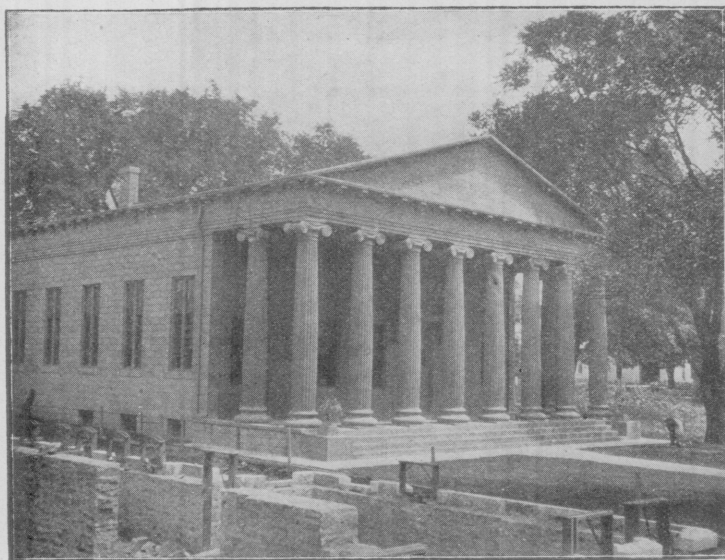


Fig. 85.—Front View of Christian Science Temple, Columbus, Ohio.

ROOFS.

Nassau County Court House.—A description of the Nassau County Court House, at Mineola, Long Island, will probably illustrate the use of steel concrete in many of its forms as well as anything that has been done in that line. This county had experienced the loss of its records by fire, as many counties have throughout the United States, so that the



Fig. 86.—Detail of Pillars.

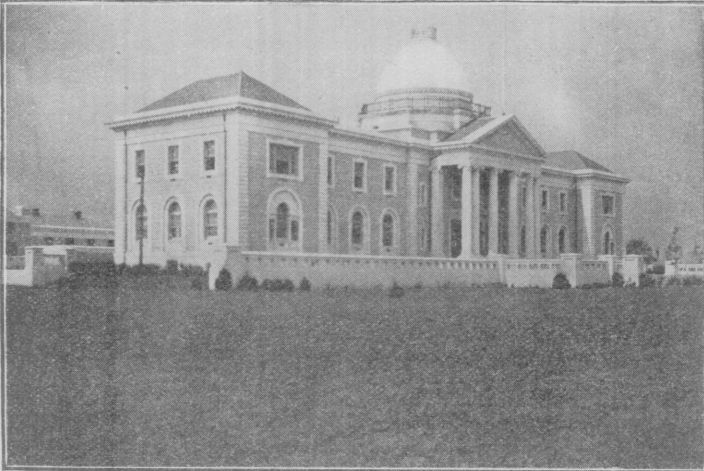


Fig. 87.—Court House at Mineola, Long Island, N. Y.

county officials decided to erect a fireproof building. This building was erected, in 1901 and 1902, entirely of steel concrete. It is a two story building erected in the form of a **L**. The main building is 176 by 37 feet and the central stem is 60 by 52 feet in area. The whole is surmounted with a circular dome 25 feet in diameter and 62 feet high. The foundations, walls, columns, floors, roof, dome and ceilings are all of steel-concrete, monolithic in construction. The body and trimmings of the exterior walls are beautifully contrasted by constructing the body of concrete composed of crushed trap rock while the trimmings are of crushed marble concrete. The porch columns, interior columns, cornices, etc., are of the marble concrete. The interior walls are covered with a hard white plaster placed directly upon the concrete surface. The exterior walls, the concrete fences and gateways are bush hammered, giving a fine natural stone appearance. The floors in the building are of concrete in the proportion of 1 part cement, 2 sand and 3 parts crushed stone. They are $2\frac{1}{2}$ inches thick, in panels 20 to 30 inches wide and 12 to 28 feet in length. The floors in the main portions of the building have 2



Fig. 88.—Rotunda in Mineola Court House.

inch top slabs and $1\frac{1}{2}$ inch ceiling slabs resting on concrete beams spaced from 17 to 24 inches apart. No steel is used in the floor and ceiling slabs, but steel bars are used in the top and bottom of the beams.

In the rotunda there is a circular light-well 14.5 feet in diameter, around which the upper floors are supported by a circular concrete girder $10\frac{3}{4}$ inches wide and $20\frac{3}{8}$ inches deep, having a single $\frac{3}{4}$ inch steel bar imbedded in the concrete at the top and bottom. From this girder radiate other concrete girders to the side walls, thus giving the circular girder support. The floor in the rotunda is $3\frac{1}{2}$ inches thick made in 8 by 10 foot panels, reinforced with $\frac{1}{4}$ inch bars spaced three inches apart and bedded in the lower portion of the concrete about $\frac{3}{4}$ inch from the lower face.

The exterior walls are hollow, with occasional ribs connecting the outer and inner wall slabs. The hollow spaces contain heating and vent ducts. The outer wall slab is 3 inches thick and the inner 2 inches, with 15 inch air spaces between. The concrete used was made of 1 part cement, 2 parts sand and 4 parts crushed stone.

The roof is like the floors, but is lighter and has no ceiling slab beneath the concrete rafters, except over the large court room where the vaulted ceiling with a clear span of 49 feet has a 2 inch shell connected with the 2 inch roof shell by 5 inch transverse ribs spaced 3 feet apart in the clear. A shrinkage joint is provided at the ridge to care for expansion and contraction.

The dome roof has a solid shell 3 inches thick without ribs and reinforced by $\frac{1}{4}$ inch steel bars, both horizontally and radially, the horizontal bars being 12 inches apart and the radial bars 12 inches apart at the base of the dome. The rods are $\frac{3}{4}$ inch from the outside of the shell at the base of the dome and cross over at about three-fifths of the height of the dome to $\frac{3}{4}$ inch from the inside of the shell. Plaster forms were used for the outer part of the dome and for the decorative features, while wooden forms were used for the inner surface of the dome and the work in general.

The building contains 70,000 cubic feet of concrete and 80,000 pounds of steel, and cost about \$106,000.00. The specifications required a sectional area of one square inch of steel and four square inches of concrete for each 2,000 pounds of tensile and compressive strain respectively.

Unscreened broken stone, having a maximum diameter of $\frac{3}{4}$ inch, with Atlas Portland cement was used in the concrete. Figures 87 and 88 illustrate this work.

To illustrate the Hennebique system of concrete floors and roofs, a section of Mr. W. C. Sheldon's five story residence on Fortieth street, New York, is presented in figure 89. The extreme lightness of the construction is clearly shown.

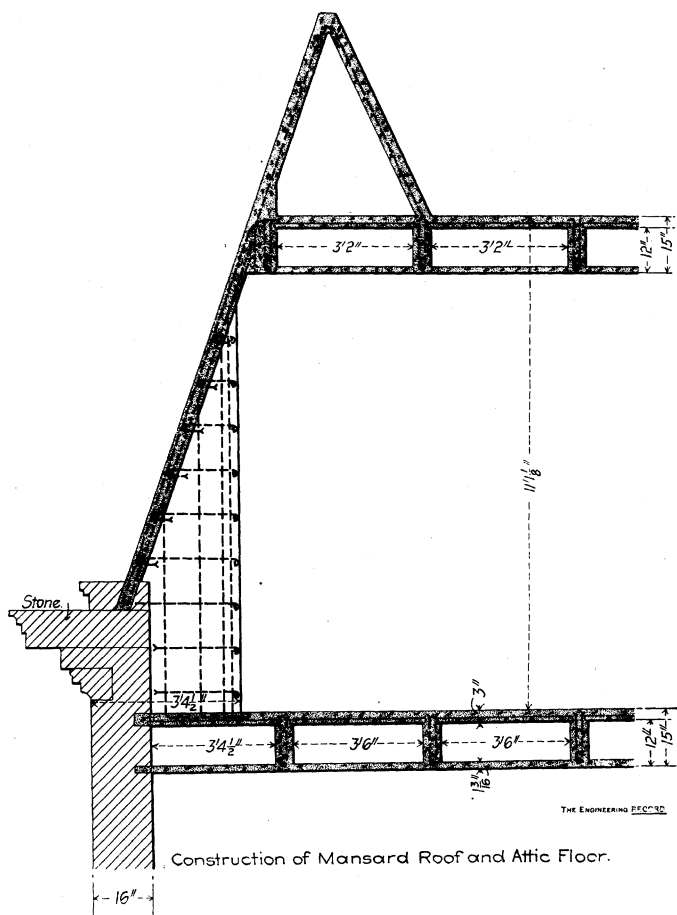


Fig. 89.—Mansard Roof and Attic Floor, W. C. Sheldon's Residence, New York.

CHIMNEYS.

Figure 90 illustrates the tallest concrete chimney in the United States. It was erected in 1902 for the Pacific Electric Railway Company's power house in Los Angeles, Cal. It is built of steel concrete and is 180 feet high, 18 feet in diameter at the base and 15 feet in diameter above the shoulder with an interior diameter of 11 feet. It is built of two shells; the outer shell is 9 inches thick for the bottom third of its height, 6 inches thick for the middle third and 5 inches thick for the top third; and the inner shell, which is to provide for the expansion and contraction due to the heated gases from the boilers, has a bottom thickness of 5 inches and a top thickness of 4 inches. It is designed to give draught capacity for a 6,000 horse-power plant. The two shells have no connection with each other. The material was mixed by machinery upon the ground and hoisted through the interior to the scaffold which was arranged to be extended readily after each day's work. An exterior scaffolding was swung just below the working forms to catch

any one who might accidentally fall. The proportions of concrete used in the inner shell were of 1 part cement, 2 sand and 4 stone; in the outer shell, 1 part cement, 2 sand and 6 stone.

There are four or five other large concrete chimneys in this country: One at South Bend, Ind., one for the Algonquin Hotel in Dayton, Ohio, and two in New Jersey, one of which, at the Pacific Coast Borax Company's plant, is 150 feet high and 7 feet inside diameter; the other, at the Central Lard Company's plant, is 108 feet high and 8 feet inside diameter.

TANKS, SILOS AND ELEVATORS.

Steel concrete has been used for gas-holder tanks, coal bins, lime bins, cement storage bins, water towers, grain elevators, silos, etc. As



Fig. 90.—The Tallest Concrete Chimney in the United States (in Process of Construction), the Pacific Electric Railway, Los Angeles, Cal.

these all have similar form and require the same character of construction, space will only be taken to describe a couple of forms.

Illinois Steel Company's Cement Bins.—In 1902, the Illinois Steel Company erected four steel concrete cement storage bins at South Chicago. They are 25 feet in diameter and $53\frac{1}{2}$ feet high, set upon the four corners of a square. They are mounted upon columns, 15 feet above the ground and the tanks being connected together, the space between them is also used for storage purposes. The walls of the tanks are 7 inches thick at the bottom and 5 inches thick at the top. The reinforcing

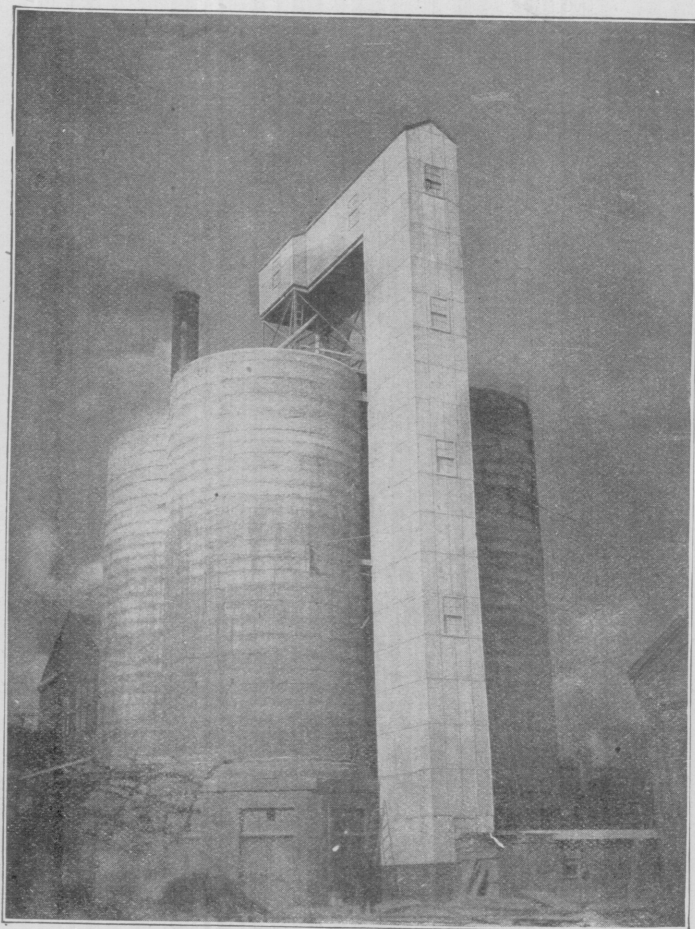


Fig. 91.—Concrete Bins for Storing Cement,
Illinois Steel Company, South Chicago, Ill.

metal used was a 1 by 4 inch No. 9 wire mesh attached to and stiffened by circumferential rods spaced 4 inches apart vertically and varying in size

from 1 inch in diameter for the bottom rods to $\frac{3}{8}$ inch in diameter for those used at the top. The roof is 2 inches thick. The supporting columns are steel railroad rails imbedded in concrete and resting upon a foundation of concrete 3 feet thick having wire mesh imbedded in the bottom portion. The bottom of the tanks have a conical shape with the apex of the cone up and are 4 inches thick. The concrete in the foundation was composed of 1 part cement, 3 sand and 4 parts stone, and the concrete for the tank shells was 1 part cement and $3\frac{1}{2}$ parts sand. The work was carried on day and night in order to prevent the necessity of placing fresh concrete upon set concrete faces. The capacity of the tanks is 25,000 barrels of cement.

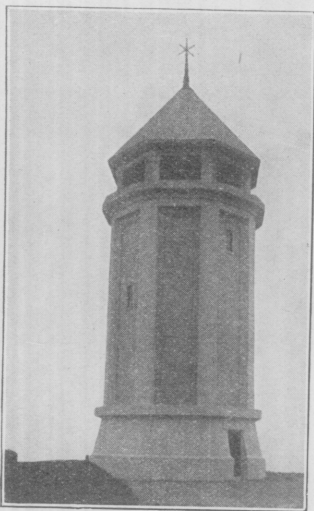


Fig. 93.—Water Tower, Revere, Mass.

Water Tower, Boston Harbor.—At Fort Revere, at the entrance to Boston harbor, the first steel concrete water tower built in this country has just been completed, although several have been built in Europe during the past few years. It consists of a large steel concrete tower 93 feet high with foundations 5 feet deep, enclosing and supporting a steel concrete water tank 50 feet high and 20 feet in diameter. The wall of the tank is 3 inches thick at the top and 6 inches thick at the bottom, coated inside with one inch of 1 to 1 cement mortar, and on the outside with $\frac{1}{4}$ inch of the same. The bottom of the tank is 4 inches thick. The wall is reinforced by two systems of vertical 5-16 inch rods spaced 2 inches apart transversely and 16 inches apart circumferentially, also by two sets of horizontal hoops of $\frac{1}{2}$ inch bars spaced $1\frac{3}{4}$ inches apart vertically at the bottom and gradually increasing the spacing to $3\frac{3}{4}$ inches toward the top, the upper portion being $\frac{3}{8}$ inch bars space 3 to $3\frac{3}{4}$ inches apart.

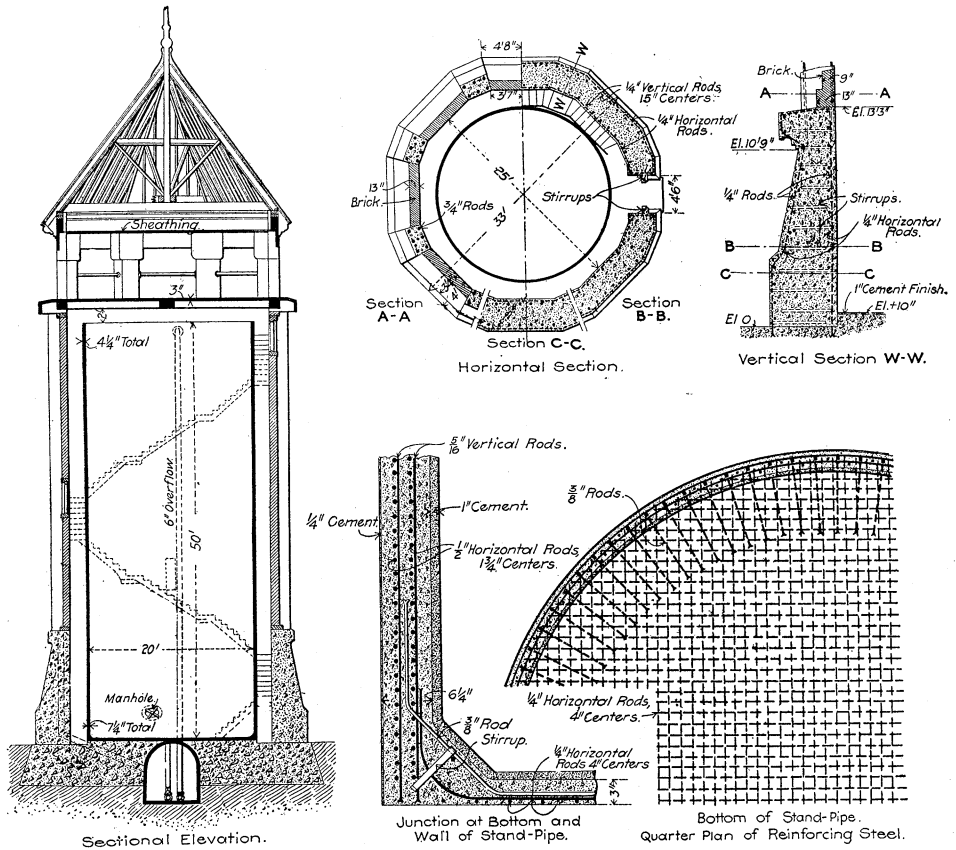


Fig. 94.—Details of Water Tower, Revere, Mass.

The concrete was mixed in the following proportions: For the foundation 1 part cement, 3 parts sand and 6 stone. For the tower 1 part cement, 2 parts sand and 5 stone. For the water tank 1 part cement, 2 parts sand and 4 stone.

Figures 91 and 92 show the plans and a photograph of the Illinois Steel Company's cement bins. Figures 93 and 94 show the plans and a photograph of the Revere water tower. Figures 95 and 96 illustrate the use of concrete for water tanks and silos.

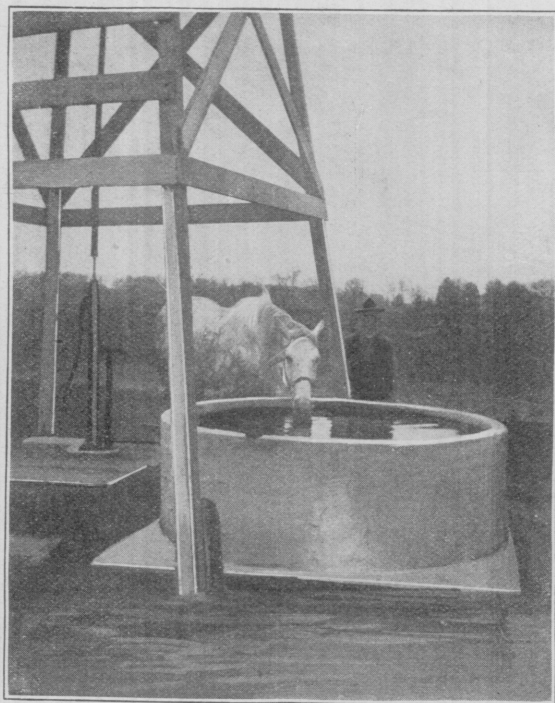


Fig. 95.—Water Tank for Stock at Clarke Lake, Michigan.

BRIDGES AND CULVERTS.

The First Concrete Bridge.—The first concrete bridge constructed in the United States was built over Pennypack Creek on Pine Road, Philadelphia. It was designed by Mr. C. A. Frik, superintendent of bridges in Philadelphia, and was built in 1893.*

The bridge consists of two spans each 25 feet $4\frac{3}{4}$ inches long, with a rise of 6 feet 6 inches. It is 34 feet wide and carries a 26 foot macadam road. The arches are 2 feet, 3 inches deep at the crown. The spandrel walls and the faces of the arches are molded to represent Ashlar masonry, and then pebble dashed for a surface finish. Imported Portland cement

**Engineering News*, Sept. 7, 1893.

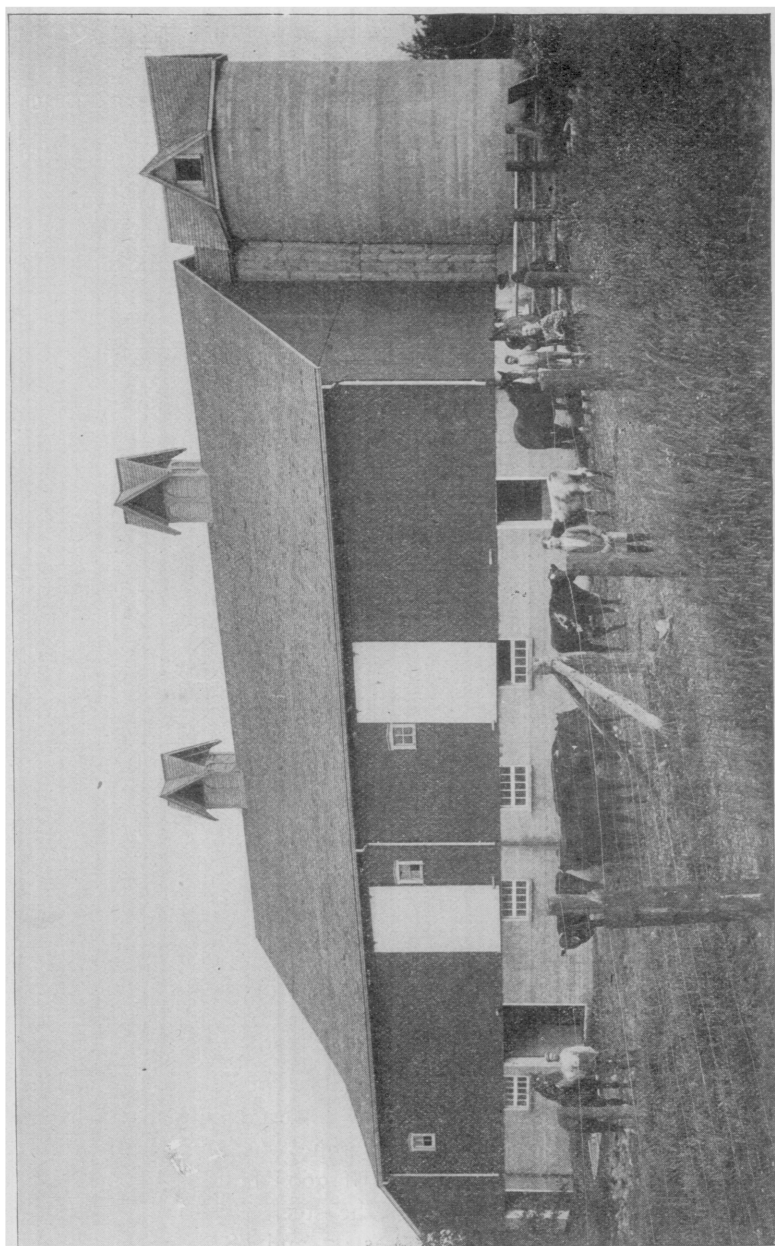


Fig. 96.—Cement Silo on Thomas Hodgins Farm, London, Ont.

was used in the work. To strengthen the work, $1\frac{1}{2}$ inch wire mesh was placed about 2 feet apart horizontally and vertically in the concrete, the wire being $\frac{1}{4}$ inch in diameter. The cost of the work was:

For 680 cubic yards of concrete at \$9.30 per cubic yard.....	\$6,324 00
Macadam, appurtenances, etc.....	2,338 00
Total cost of bridge.....	\$8,662 00

Fall Creek Bridges, Indianapolis.—The Melan arch was among the pioneers in steel concrete bridge construction. In the Melan construction steel I-beams are imbedded in the concrete, the base of the I-beam being from 3 to 5 inches from the intrados of the arch.



Fig. 97.—A Melan Concrete Bridge, Indianapolis, Ind.

The following description of the bridges built in 1900, over Fall Creek, Indianapolis, where Illinois and Meriden streets cross that creek, will illustrate the Melan system applied to bridges. The city had been burdened for years with the great expense of maintenance and repairs upon the many steel bridges within the corporate limits, until at last the authorities decided to replace the bridges at these points with permanent structures. Bids were invited upon three forms of bridges—steel girders, steel concrete and stone bridges. The bids upon steel bridges were the lowest, but were rejected because steel girder bridges lack both in beauty and durability. The lowest bid upon concrete was \$105,340.00, while the lowest bid upon stone was \$140,996.00, although close at hand there was an abundance of good building stone. One of the completed bridges, also one with the steel skeleton in place ready to receive concrete, is shown in figures 97 and 98.

The proportions of the concrete used in the back walls, spandrels and piers were, 1 part cement, 3 parts sand and 6 parts gravel. For the arches, 1 part cement, 2 sand and 4 parts gravel were used. The gravel and sand were taken directly from the bed of the stream.



Fig. 98.—A Melan Bridge in Process of Construction.

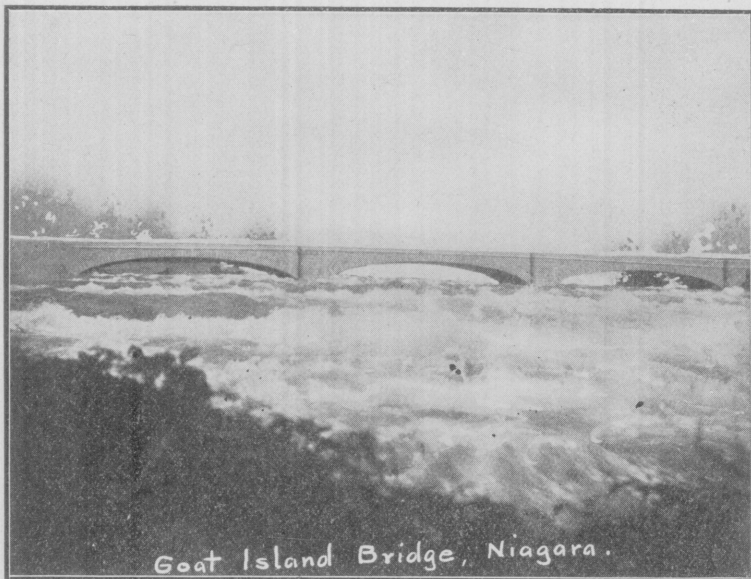


Fig. 99.—Goat Island Bridge, Niagara Falls, N. Y.

The I-beams were 10 inch 25 pound beams, spaced 3 feet center to center. The arches were 18 inches thick at the crown and 21 inches thick 10 feet from the spring line. The spans were 74 feet with a rise of $9\frac{1}{2}$ feet. It required but six months to build the two bridges.

Goat Island Bridge, Niagara—This bridge was erected in 1901, by the United States. The length of the bridge from the main land to Green Island, the small island where the main structure ends, is 371 feet. The bridge is divided into three spans: two are $103\frac{1}{2}$ feet and one is 110 feet long, supported by piers $13\frac{1}{2}$ feet wide. The rise of the elliptical arches is 10 feet for the two short spans and $11\frac{1}{2}$ feet for the longest span. The roadway is 20 feet wide with $9\frac{1}{2}$ foot walks on each side. This bridge is built after the Thatcher design with steel ribs spaced 3 feet apart in the concrete. The steel ribs are built up of $\frac{3}{4}$ by 6 inch steel plates, one near the top of the arch and the other near

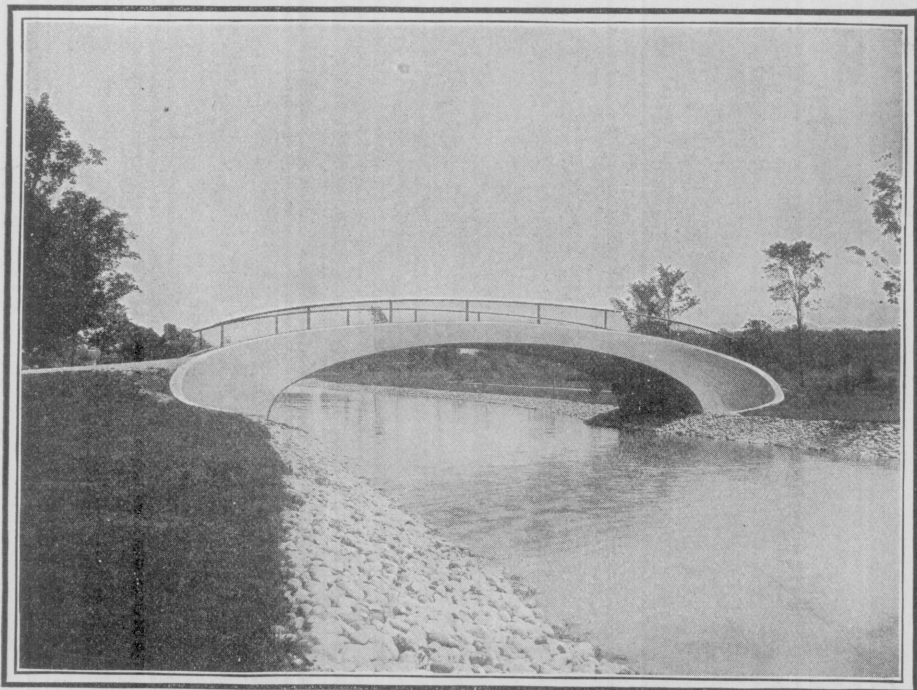


Fig. 100.—Concrete Bridge at Summer Home of P. D. Armour, Jr., Oconomowoc, Wis.

the bottom. They are connected with $\frac{5}{8}$ or $\frac{3}{4}$ inch iron rods about every 30 inches. The top and bottom plates or bars follow the general outlines of the arch so that at the haunch of the arch the steel members are about 6 feet apart. High oval headed rivets, spaced 6 or 7 inches apart, are riveted into the top and bottom plates to give greater bond between the steel and concrete. There are 13 of these steel

ribs placed in the bridge. The whole arch is 38 inches thick at the crown and 70 inches near the haunch. The water is about 6 feet deep where the bridge stands and has a velocity of nearly 30 miles per hour. The bridge cost \$102,070.00. Figure 99 shows the bridge.

Oconomowoc, Wisconsin.—A very neat concrete bridge was built in 1899 for Mr. P. D. Armour, Jr., at his summer residence near Oconomowoc, Wisconsin.* It has a span of 21 feet, a rise of 6 2-3 feet, and width of 15 feet. The arch is 5 inches thick, reinforced by three ribs 2 feet wide and 4 inches thick. A pair of flat iron bars, $\frac{3}{4}$ inch by $3\frac{1}{2}$ inches, is placed at either side of the bridge conforming to the arch. These are latticed together forming steel trusses, the bottom of which are connected across the bridge by $\frac{1}{2}$ inch round iron rods spaced 18 inches apart and $\frac{1}{2}$ inch above the face of the concrete. Number 16 expanded metal, $2\frac{1}{2}$ inch mesh, was laid over these rods. The concrete, composed of 1 part cement, 3 parts torpedo gravel and 4 parts of $\frac{3}{4}$ inch limestone, was then tamped in place. The surface coat was composed of 1 part cement, 1 part granite screenings and 1 part torpedo gravel. The facing is 1 inch thick and was spread upon the form before the concrete was laid. The centering was removed in nine days and heavy loads were hauled over the bridge. Figure 100 illustrates the beauty of the bridge.

Chatellerault Bridge, Vienne, France.—The Hennebique system of steel concrete is well illustrated in the construction of the Chatellerault

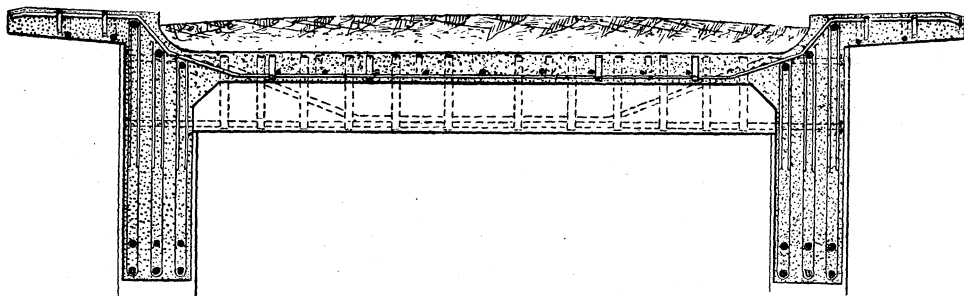


Fig. 101.—A Cross Section of a Bridge Showing Hennebique System.

bridge in France. This bridge has three spans, two of 131 feet and the other 164 feet in length. It was given several severe tests and records were taken of the deflections. A moving load consisting of road rollers and heavily loaded wagons, altogether equal in weight to 308,000 pounds, was driven across the bridge. These loads were again driven across after large wooden strips had been placed in the roadway in order to produce a series of shocks or blows. The maximum deflection upon the two shorter spans was 6 mm., and for the center arch 10 mm., or slightly

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less than 13-32 inch. Two hundred and fifty soldiers crossed, marching in quick step, and recrossed at "double time" in order to test the bridge for vibration, which it was found to stand remarkably well, Figure 101 shows the method of construction and figure 102 shows the complete bridge.

A seven span concrete bridge at Dayton, Ohio, completed in 1903, which is 56 feet wide and 588 feet long, cost \$140,000.



Fig. 102.—Chatellerault Bridge, Vienne, France.

RETAINING WALLS.

In the construction of the Paris Exposition of 1900, it was found necessary to depress one of the streets near the exposition grounds to better accommodate the visitors. This street was to be depressed about 18 feet below the surface levels; and because of the character of the debris and filled ground through which the cut was to be made would have required expensive, heavy masonry for retaining walls if the ordinary gravity section were used; hence the engineers decided to use "armored concrete."

The retaining walls are divided into panels 19.7 feet in length, and extending back into the ground from the back of each panel, are three concrete buttresses. Connecting these buttresses at a point midway from the top to the bottom is a horizontal concrete beam from 4 to 9 inches thick and about 4 feet wide. The face wall rests upon another

horizontal beam similar to the above described beam and 4 feet 4 inches wide, which extends in front of the face wall about $2\frac{1}{4}$ feet and is connected by low buttresses to the face wall. This projection is about $2\frac{1}{2}$ to 3 feet below the street level. The whole mass of concrete which is 4 to 6 inches thick is reinforced and connected by a system of Hennebique steel bars.

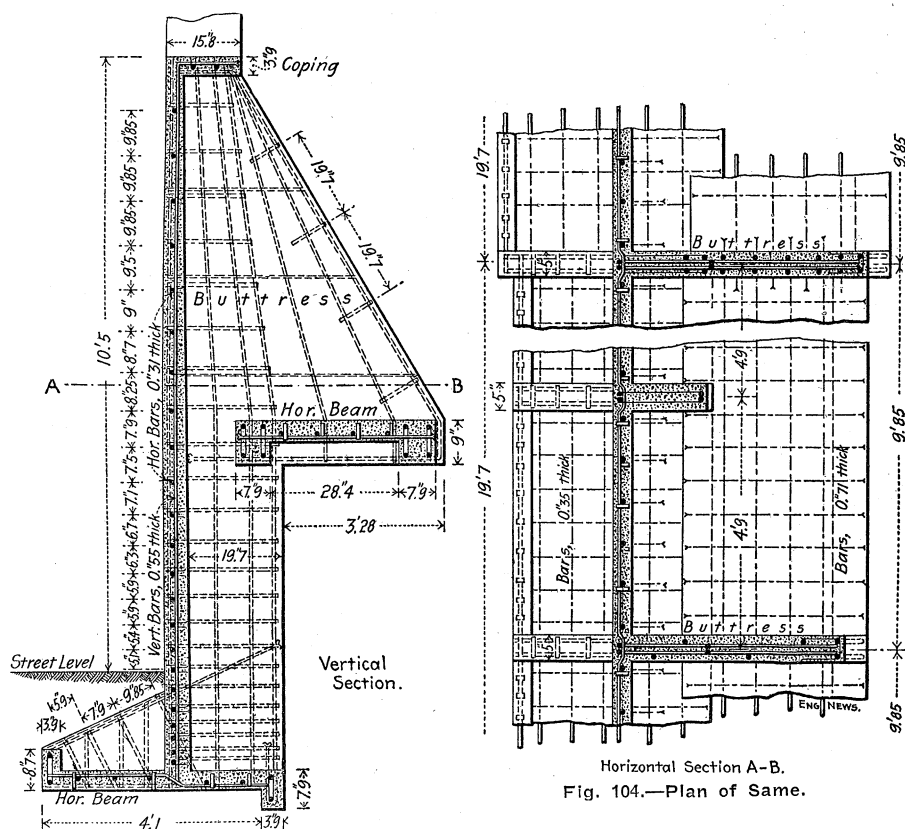


Fig. 103.—Section of Retaining Wall Used at Paris Exposition, Hennebique System.

By the arrangement of the horizontal beams the retaining wall is aided in supporting the thrust of the earth behind by the weight of the earth resting upon the beams. The location of the beams is such as to break up and reduce the thrust upon the thin vertical face wall. A portion of the tendency to overturn is also taken up by the forward portion of the lower beam and its bracing buttresses. The two figures 103 and 104 illustrate the construction better than the description.

In 1897, Messrs. Lehman and Moller invented a simple but efficient retaining wall which was patented in Denmark, Sweden and Norway, by a patent dated April 21, 1899. It consisted in a thin L shaped section of concrete, reinforced by steel, resting upon the shorter arm of the L and

depending upon the weight of the earth resting upon the lower arm, to overcome the thrust of the earth against the upright arm. See figure 105.

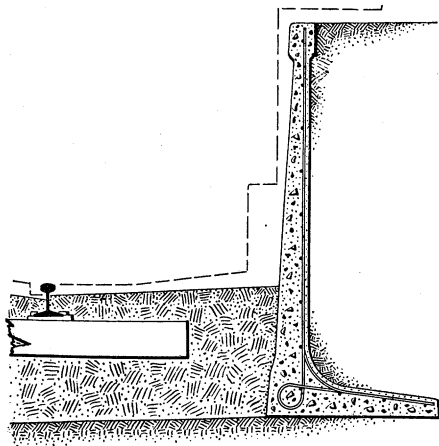


Fig. 105.—Section of Retaining Wall, Lehman's System.

In 1901, Mr. Frank A. Bone constructed a retaining wall upon similar lines, but not so light, at Blacklick, Ohio, upon which he secured patents in the United States. Figure 106 shows the cross section

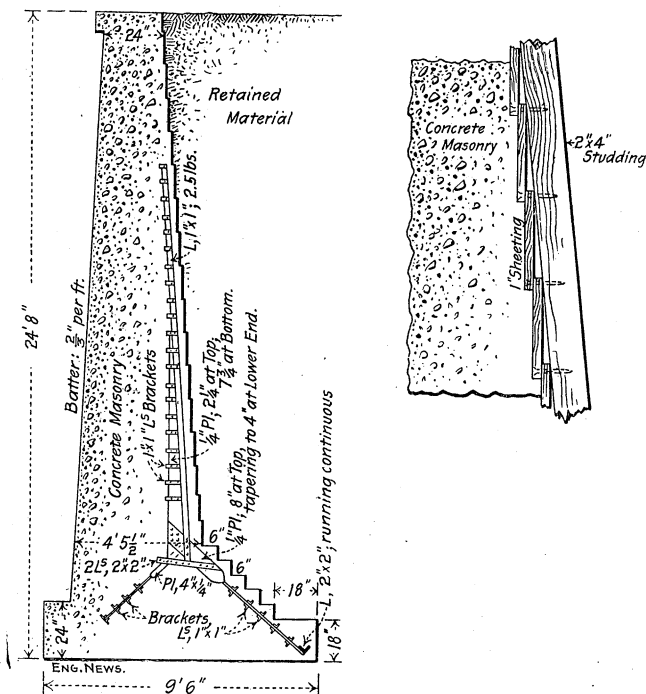


Fig. 106.—Section of Wing Wall, Bone's System, Constructed at Black Lick, Ohio.

of the Black Lick retaining wall. The steel ribs were spaced 4 feet apart throughout the wall and connected with 2 by 2 inch angle irons running horizontally through the mass as shown in the figure.

TUNNELS.

Reinforced concrete is used very often for the lining of tunnels. It is very similar, in general, to the lining of plain concrete heretofore described, its chief advantage being in unstable soils or in soft or stratified rock where falls or squeezes occur. Here the steel bars or members aid in supporting the pressure until the concrete has become perfectly set and also supply the tension members which aid the lining to withstand distortion.

Tunnel Under River Spree, Berlin.—A notable example of the use of steel concrete is in the tunnel under the River Spree at Berlin, Germany. It is 2,017 feet long and lies 40 feet below the level of the river. It is formed of a cast steel cylinder, 13.12 feet in diameter made into rings, set together and covered with $3\frac{1}{8}$ inches of cement mortar upon the outside, and $4\frac{3}{4}$ inches upon the inside, with a heavy concrete floor. The steel rings vary from 1.64 to 2.13 feet in width.

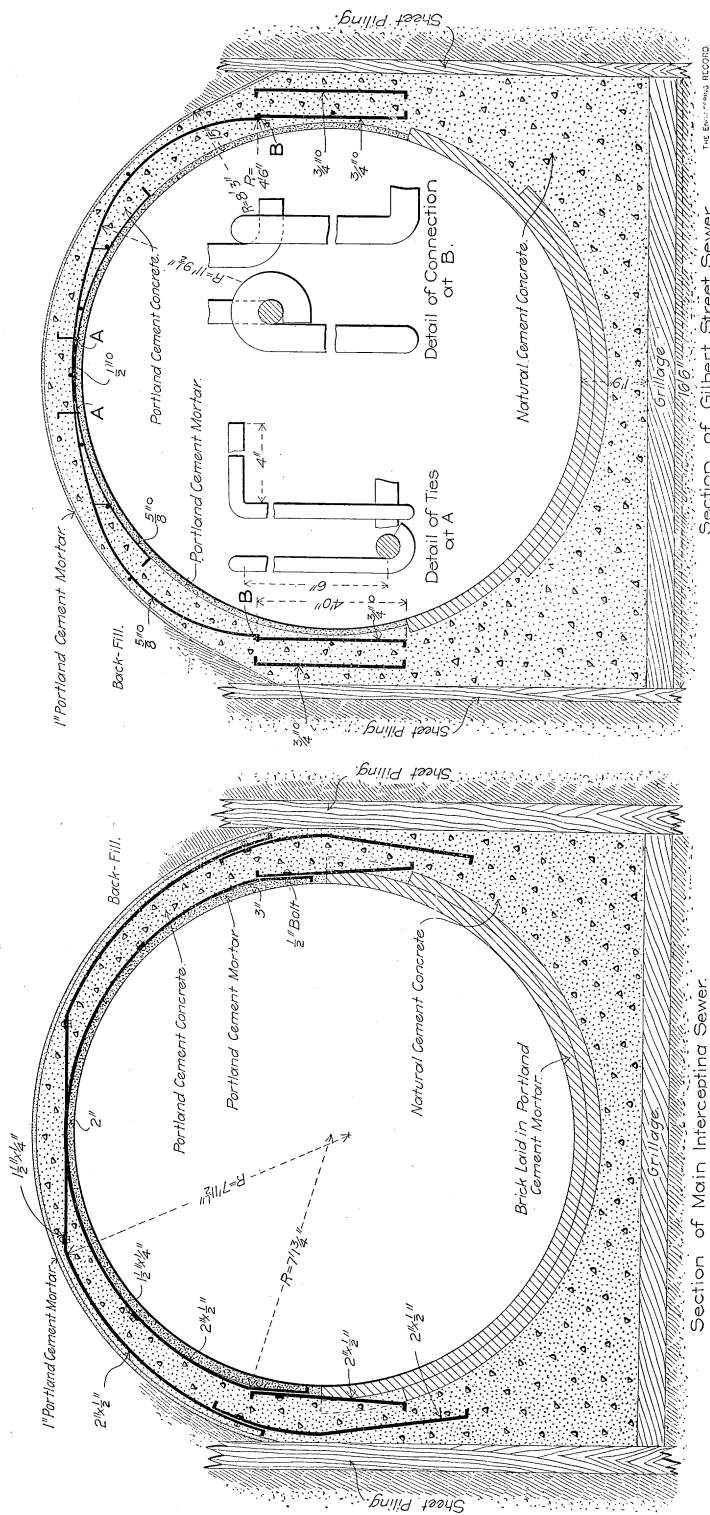
SEWERS.

There are many forms of steel concrete used in sewer work. Expanded metal has been frequently used, being imbedded in concrete either just over the arch, or encircling the entire barrel.

Plain round and square bars, angle irons, I-beams and the Monier wire mesh have been used under various conditions.

One system that is being extensively used in Cleveland and Columbus, Ohio, will be briefly described here. It is known as the Parmley patent.

It consists of a system of two sets of round or flat steel bars imbedded in the concrete. The sets are staggered, one set being placed near the inner lining of the sewer, while the other set is near the outer side of the concrete walls. Both sets, however, are kept close to the inner surface of the crown of the arch and only extend downward to a point about one-fifth the diameter of the sewer below the center line. Longitudinal rods are also used to aid in distributing the stresses. To overcome the disadvantage of having the bars continuously in the way during the construction of the invert, the bars are cut into pieces and either punched for bolting or bent to engage hook and eye fashion. The shorter pieces are set into the concrete vertically, extending above and below the spring line, the arched piece being set in place when everything is ready to concrete the arch. For smaller sewers, the iron or steel rods, which are small, can be brought upon the work in merchantable lengths and cut and bent over forms as the work progresses.



THE BUILDING RECORD

Section of Gilbert Street Sewer.

Fig. 107.—Cross Section Main Intercepting Sewer, Cleveland, Ohio.

Cleveland Main Intercepting Sewer.—The Main Intercepting Sewer in Cleveland, is built on the Parmley patent system. It is $13\frac{1}{2}$ feet in internal diameter, and $3\frac{1}{2}$ miles of it are under construction. For nearly two miles it is 35 to 44 feet deep and only 17 feet away from the center line of the Lake Shore and Michigan Southern Railway tracks. "Two staggered rows of 2 by $\frac{1}{2}$ inch soft steel anchor bars, 15 inches apart on centers, were built into each side wall, and projected above it to receive the main tension bars." The transverse tension pieces were afterward bolted to these anchor bars and 8 lines of horizontal pieces $1\frac{1}{2}$ by $\frac{1}{4}$ inch in dimensions were bolted to the transverse ribs.

After the steel was in place over the forms, 3 inches of cement mortar was laid upon the forms, enclosing the inner rods, then the concrete was rammed upon this mortar and the outside finished with one inch of cement mortar. The concrete for the arch was made of 1 part cement, 3 sand and $7\frac{1}{2}$ crushed stone. The average price for this sewer is "about \$62.00 per lineal foot as compared with \$75.00 per lineal foot bid for ordinary brick construction." Figure 107 shows the work in detail.

A portion of the Central Relief Sewer in Columbus, Ohio, is being built on the same system of construction.

STEEL-CONCRETE WATER PIPE.

In a new water power plant at Champ, near Grenoble, France, 6,888 feet of a penstock, which conveys water to the turbines of the power plant, is constructed of steel concrete. It has a diameter of 10.82 feet and a uniform grade of 7 feet in the 1,000. The concrete portion was designed to carry a head of water of 65.6 feet. Iron bars from 0.43 to 0.87 inch in diameter are spaced at equal distances, longitudinally, around the barrel and outside of these and encircling them at right angles to the axis of the pipe are other bars from 0.24 to 0.47 inch in diameter. These longitudinal and transverse bars form meshes about 4.0 by 4.3 inches in dimensions. The pipe is from 8 to 10 inches thick. About 118 feet of pipe was built per day. See figure 108.

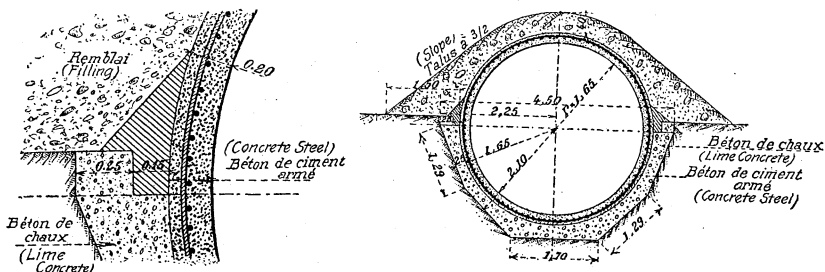


Fig. 108.—Detail of Concrete Steel Penstock.

Water Conduit for Jersey City.—The water supply for Jersey City, N. J.,* is carried for several miles through a large steel concrete conduit.

*Engineering News Aug. 30; 1900.



Fig. 109.—Section of Water Conduit, Boonton, N. J., Showing Weight Carried During Test.

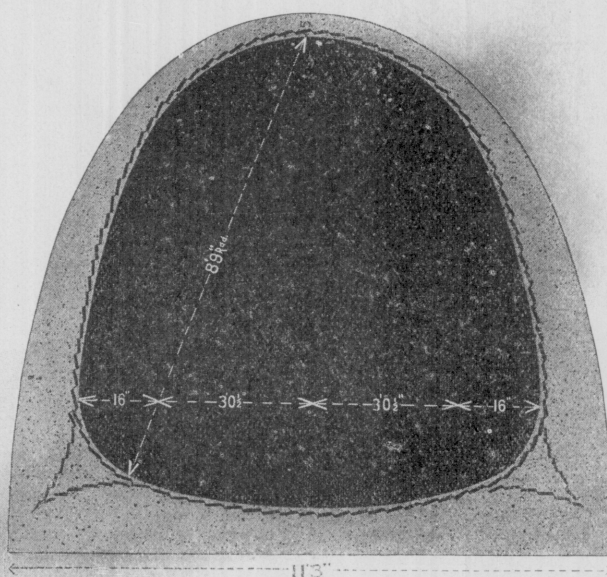


Fig. 110.—Method of Reinforcing Water Conduit at Boonton, N. J.

Several forms were designed, but after a very severe test, the form illustrated in figure 109 was adopted and used. The conduit is 8 feet, 9 inches wide, and the same in height. The crown of the arch is 5 inches thick, the haunches 10 inches thick, and the middle base, 8 inches thick. It is reinforced with expanded metal as shown in figure 110. It required one cubic yard of concrete per lineal foot of conduit.

It may be of interest to give a brief description of the test shown in the illustration. A test section 10 feet long of full size was erected in May, 1900. It was built of concrete composed of 1 part Portland cement, 2 of sand and 5 of broken stone from 1 to 1½ inches in size. Thirty days after completion it was tested. The test began at 2:45 p. m. by laying on railroad rails, one by one. "At 5:28 p. m., with a load of 21½ tons, fine horizontal cracks began to show along the extrados, but no any further signs of weakness."

"When the load had been increased to 25 tons, three rails, weighing approximately 1 ton, were twice dropped on the rails on top of the arch over one end of the latter. The cracks were slightly widened and new fine cracks showed in the intrados and haunches, running along the inside of the conduit section.

The total deflection at the crown of the arch was 7-16 inch. The test section stood under the 25 ton load for several weeks without showing any further signs of weakness.

POSTS.

The American Cement Post Company of Athens, Mich., manufactures a steel or iron concrete post. Two corrugated iron straps run

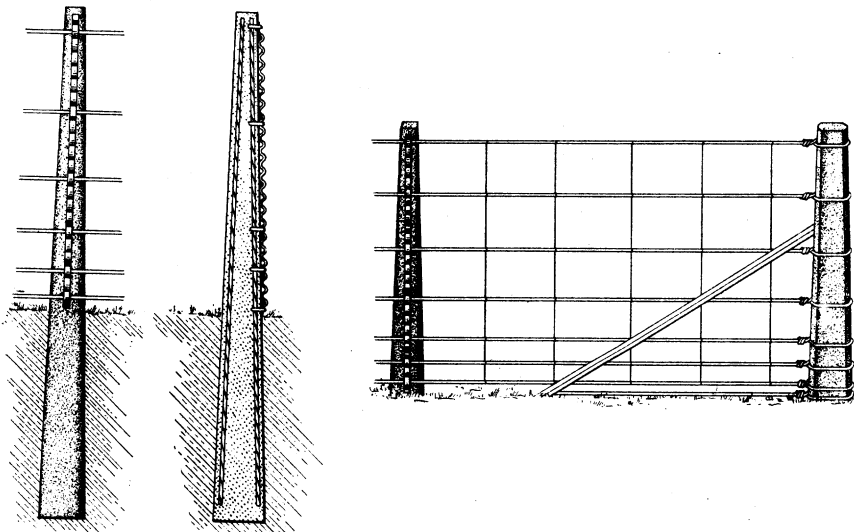


Fig. 111.—Concrete Fence Post, American Cement Post Company's System.

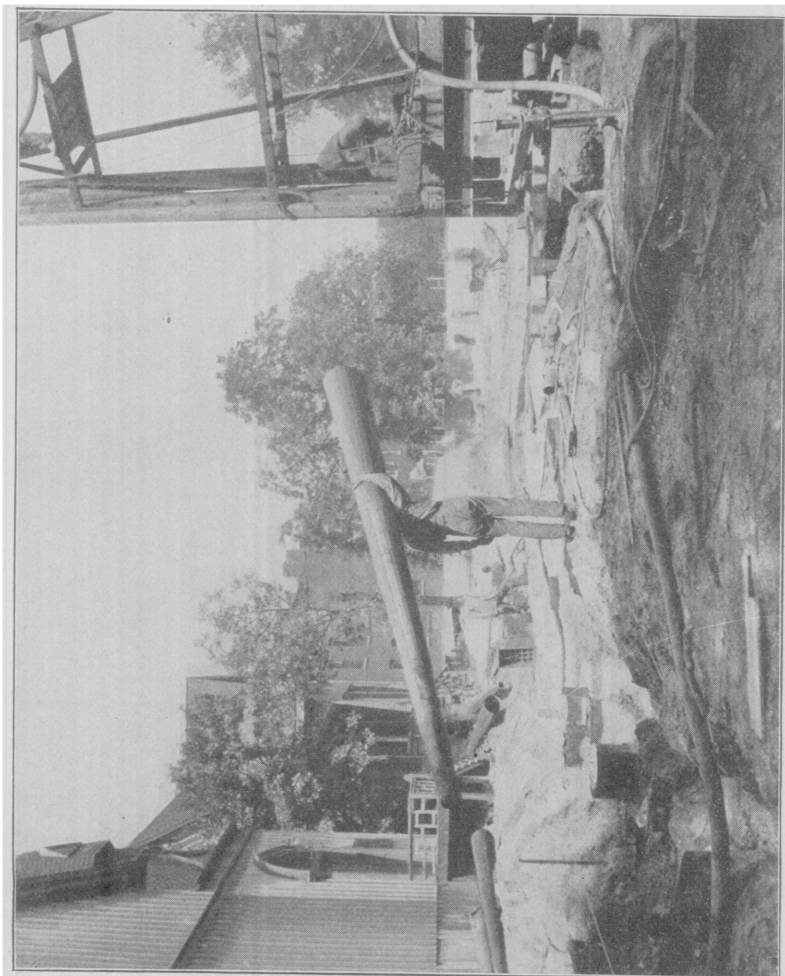


Fig. 112.—Shell for Raymond Concrete Pile, 20 Feet Long, Weighing 70 Pounds.

the entire length of the posts, doubling over at the top and bottom as shown in the accompanying illustration, figure 111. Wire is wrapped around one of these straps and looped out sufficiently beyond the surface of the cement to form attaching loops, either for barbed or net wire fencing, or for common fence boards. A special machine is used for compressing the concrete into the forms.

Corner posts are made $8\frac{1}{2}$ feet long, 8 inches square at the base, and 6 inches square at the top, and weigh about 500 pounds. Such posts cost from 30 to 35 cents a piece. The line posts are much lighter, being $7\frac{1}{2}$ feet long, $3\frac{1}{2}$ inches square at the bottom, $2\frac{1}{4}$ inches at the top and weighing about 60 pounds. These posts cost from 8 to 12 cents each.

PILES.

Several kinds of concrete piles have been employed in construction. One of the earliest uses of steel concrete piles was in the form of a steel tubular casing or wrought iron pipe sunk through yielding ground or sand to good bearing and then filled with concrete. This form was especially adapted for small highway or railway bridges, and has been quite extensively used.

Cushing's pile foundation, which consisted in driving a group of woden piles, encasing them within an iron casing extending below low water line, and then filling in all the space within the casing and around the piles with concrete, has long been used for bridge pier foundations.

Raymond Pile.—The Raymond pile consists of a steel shell 20 feet or more in length, 18 inches in diameter at the butt and 6 inches near the point, which is driven with a collapsible core. When the pile is driven, an extra blow given to one portion of the core drives in this portion collapsing the core so it can be drawn, leaving the shell in place. The casing is then filled with concrete. The cost is estimated at 50 cents per foot of pile, or \$1.00 per foot in place.

The new Carnegie library building, Aurora, Ill., is being built upon a foundation supported by the Raymond pile reaching to bed rock. These piles are encased in No. 20 sheet iron filled with Portland cement concrete of the proportions 1 cement, 2 sand and 4 crushed stone. Figures 112 and 113 illustrate the Raymond pile.

Hennebique Armored Piles.—The Hennebique armored pile consists of four round iron rods spaced 9 or 10 inches apart in a square, and tied together about every three feet with iron bars. These pieces are set in forms and concrete cast about them to form a post 14 inches square and of any desirable length. At the bottom they are shod with steel shoes as shown in the accompanying illustration. These have been used in England and upon the continent. They are especially valuable along the salt water harbors, as they can not be injured by the teredo. Such piles are

also of great benefit where the rise and fall of the water level hastens the decay of wooden piles. Figure 114 illustrates this form.

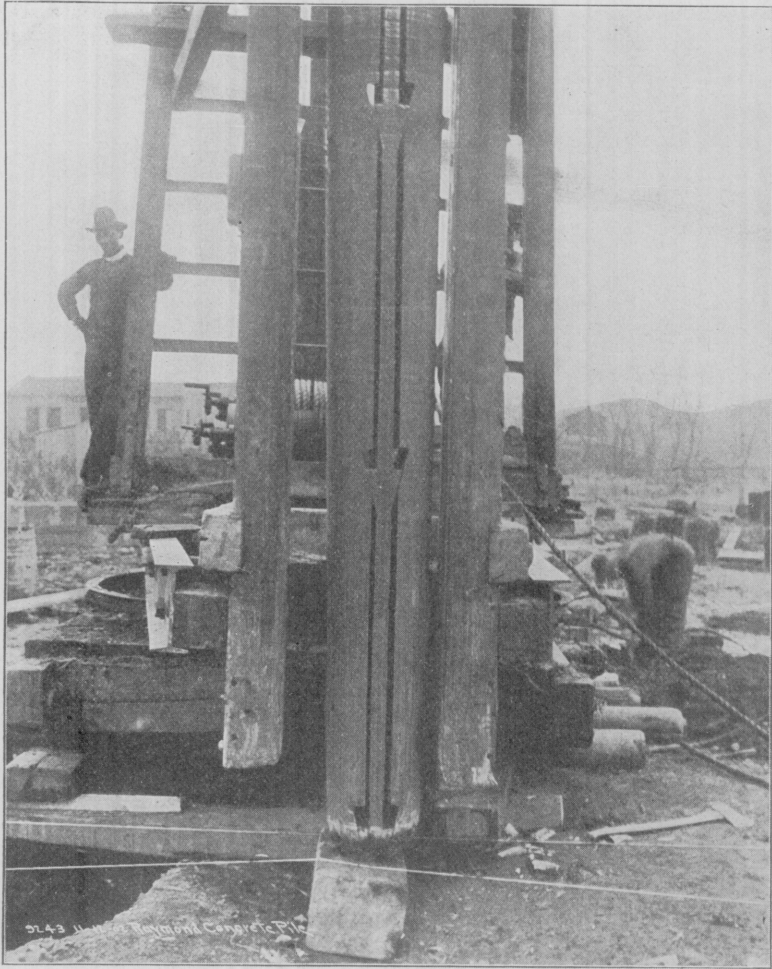


Fig. 113.—Raymond Pile Core, Which Collapses and is Withdrawn After the Shell is in Position.

ELEVATED RAILWAYS, TIES, TRESTLE BENTS, TURNTABLES, ETC.

Elevated Railways.—The St. Louis Expanded Metal Fireproofing Company have designed a steel concrete structure for elevated railroads which they claim can be constructed for less money than can a steel structure. The maintenance of such a structure should be less than one of steel and the beauty would certainly be greater. Figure 115 illustrates their design.

Ties.—In many localities, railroad ties are not easily procurable. At best they decay and wear out rapidly. Because of this, railroad

officials have long been looking for a good durable substitute for the wooden tie.

Mr. O. J. D. Hughes, U. S. Consul to Italy, reports the use of concrete ties by the Adriatic railway line. These ties are of steel concrete, $8\frac{1}{2}$ feet long, triangular in section, with apex of angle up, having full width at the rail seat. Bottom width of tie is $7\frac{7}{8}$ inches, and the weight 287 pounds. The iron bars used weigh 88 pounds. The ties cost \$2.20 apiece, about twice what a wooden tie costs. These ties have been in use for two or three years, and the railway officials, judging from the experience they have had, believe the ties will last thirty or forty years.

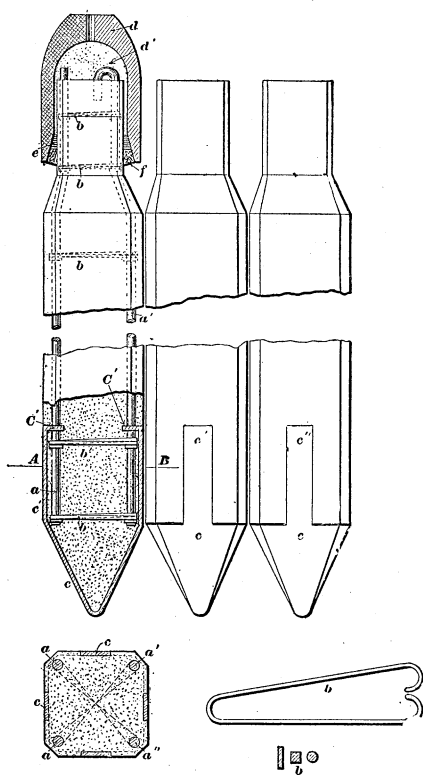


Fig. 114.—Concrete Tie, Details of Construction According to the Hennebique System.

The Pittsburg, Ft. Wayne and Chicago Railway has been experimenting with such ties at various times for four or five years. Their first attempts were not successful, the experimental work causing the ties to cost about \$8.00 apiece. Afterward, modified forms and more systematic methods of construction, led them to believe that more durable ties could be built for about \$1.00 apiece. The improved tie consisted of two channel bars 7 feet long, for the top and bottom of the tie, imbedded in concrete. Metal struts under the rail seats braced the two bars. A short piece of channel forms the rail seat through which pass

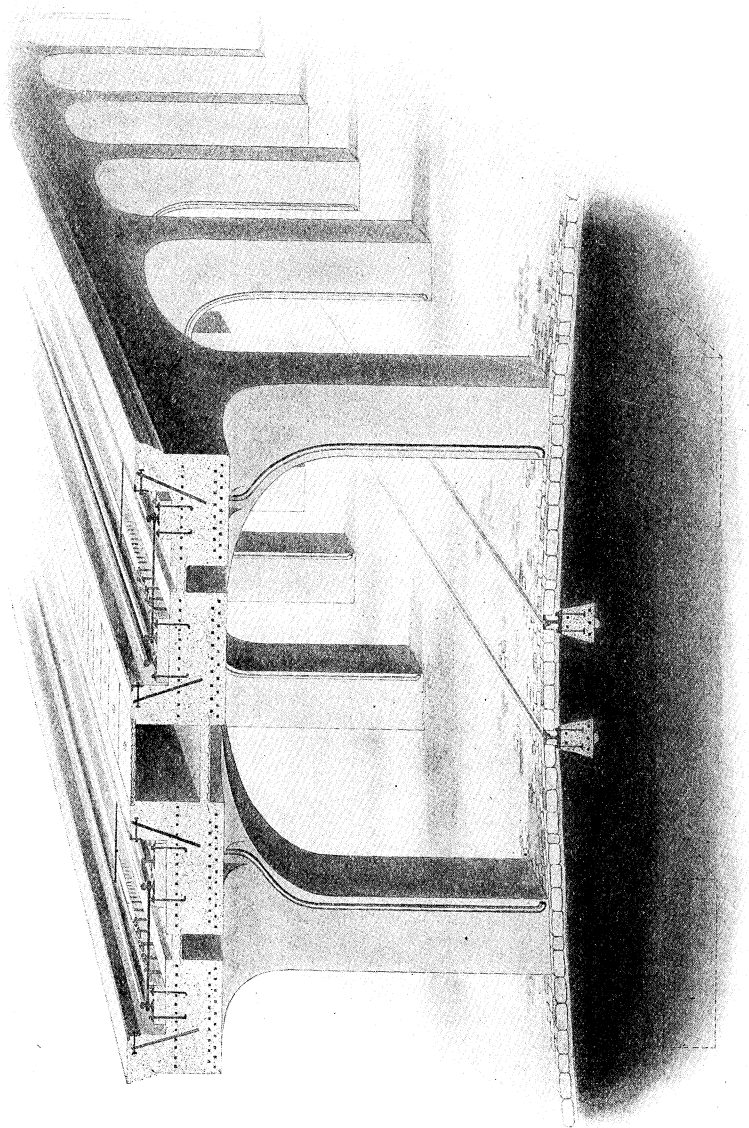


Fig. 115.—Proposed Concrete Elevated Railway System.



Fig. 116.—Concrete Ties on a German Railway.

the anchor bolts. The whole tie is 7 feet, 8 inches long, 8 inches thick and 5 inches wide on top and 8 inches wide at the bottom. It weighs complete, 300 pounds.

Quite a number of railroads are testing what can be accomplished with concrete ties, but as yet no road has definitely determined the durability of such construction. Figure 116 shows concrete ties in use on a German road.

Trestle Bents.—In the yards of the American Smelting and Refining Company, Perth Amboy, N. J., the railway tracks run over the coal and ore bins. Concrete trestle bents or walls support the tracks, forming the dividing walls for the ore bins. The bents are erected upon pile foundations, are 12 feet apart, 6 feet, 9 inches high and 12 inches thick at the top and 16 inches at ground level. At the bottom, the bent spreads out to form a footing 24 inches thick which rests upon four 13 inch piles driven 25 feet to a firm bearing. Vertical $\frac{3}{8}$ inch rods are imbedded in the concrete in two planes 8 inches apart, the rods being 18 inches apart in the plane. The forms were made of dressed lumber and allowed to remain in place 48 hours after the placing of the concrete. The concrete was a mixture of 1 part cement, 2 sand and 4 parts slag.

The cost was reported to be about the same as equivalent wooden bents with mud-sills.

Turntables and Ashpits.—A number of railroads have used concrete walls for turntables and ashpits. In the latter, especially, concrete is given a severe test. Hot cinders and ashes fill the pit and then after the walls have become heated, cold water is thrown in to quench the ashes. The sudden changes from heat to cold are very severe upon materials so unelastic as stone or concrete. Acids are also formed from the sulphurous coal ashes, yet with all of these tests, concrete has proved quite satisfactory.

At Bureau, Ill., the C. R. I. & P. railroad has constructed a five stall round house of concrete. The walls are 18 inches thick. After the forms were removed, the outside was washed with a cement washing, the inside was left as it came from the forms.

ELECTRIC FOUNTAINS.

The electric fountain at Willow Grove, Philadelphia, is constructed of concrete. It has been in operation for six years or more and seems in a fair state of preservation. One or two contraction cracks and a few places in the floor of the water basin that sounded hollow, indicated that the surface coating had not made a good union with the body of concrete. The superintendent said that no repairs had been made in the three years in which he had been in charge. The conditions are such as to give concrete a very severe test. Dry and wet, heat and cold, expansion and contraction, weathering and freezing all uniting to work destruction.

PRISON CELLS.

Concrete is used to great advantage in the construction of jail and prison cells. The steel reinforced walls are exceptionally strong and take up but small space. When floors, walls and ceilings are all made of steel concrete, it becomes a very easy matter to thoroughly cleanse a whole corridor of cells. It also prevents the spread of vermin. In cleansing, the hose with water under pressure may be used to advantage. It is also a great protection against fire.

STEEL-CONCRETE DAMS.

Fielding System.—*Mr. J. S. Fielding, Pittsburg, Pa., suggests a novel method of reducing the cost of dam construction by reducing the amount of expensive material used. He suggests using reinforced concrete constructed in rough rectangular compartments, which can be filled with earth or loose stone to give gravity stability to the dam. Figure 117 illustrates his design. The fore and back walls are connected every ten to twenty feet by cross walls in which the tie members are imbedded.

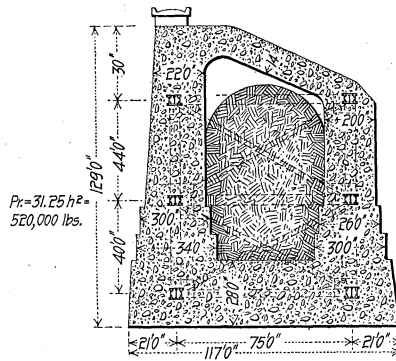


Fig. 117.—Proposed Design for Hollow Concrete Dam.

Theresa Dam.—A hollow concrete steel dam was lately constructed at Theresa, N. Y.[†] It is 120 feet long and 11 feet high. It consists of a solid concrete toe, a series of solid concrete buttresses 12 inches thick spaced 6 feet center to center, and an inclined up-stream concrete face 6 inches thick, reinforced with Thatcher bars and expanded metal. In the toe and buttresses the concrete was proportioned 1 cement, 3 sand and 6 stone, while for the water-face of the dam the proportions were 1 cement, 2 sand and 4 broken stone. Figure 118 clearly shows the construction and illustrates the great saving of material in such a form of construction.

**Engineering News* Nov. 16, 1899.

†*Engineering News* Nov. 5, 1903.

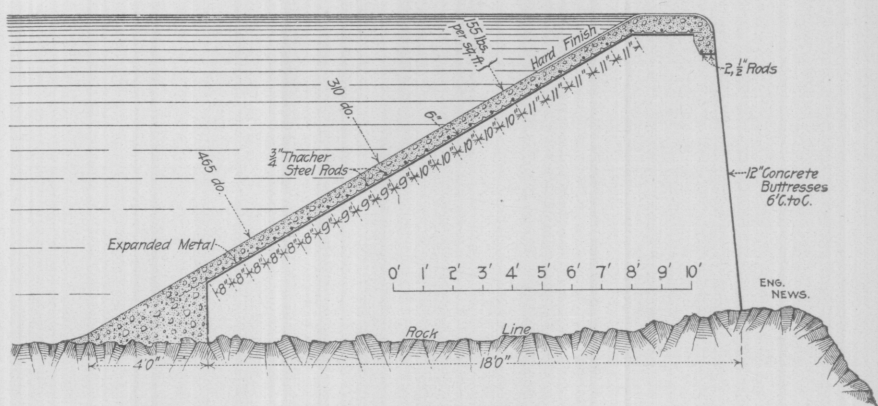


Fig. 118.—Section of Armored Concrete Dam, Theresa, N. Y.

Ithaca Dam.—A bold concrete dam was recently constructed at Ithaca, N. Y., which it is worth while to illustrate at this point in order

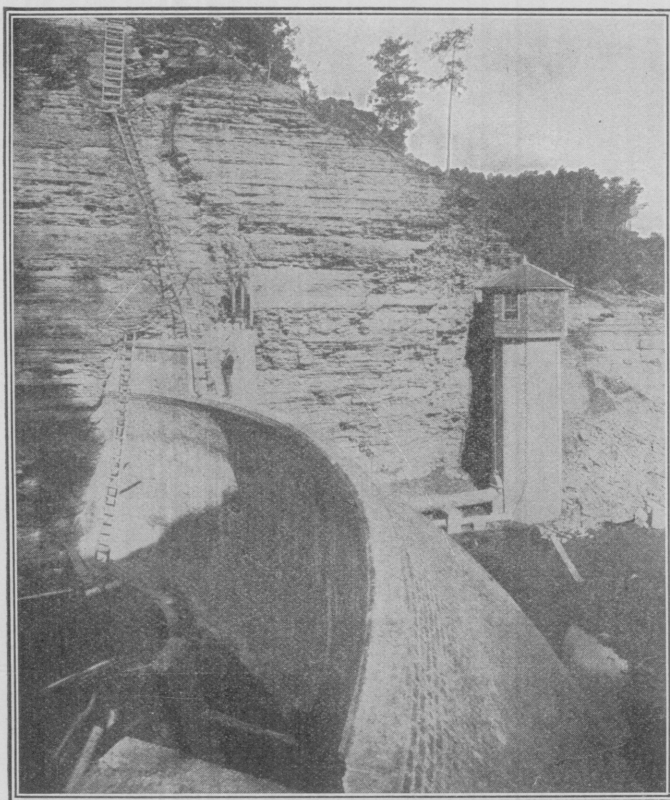
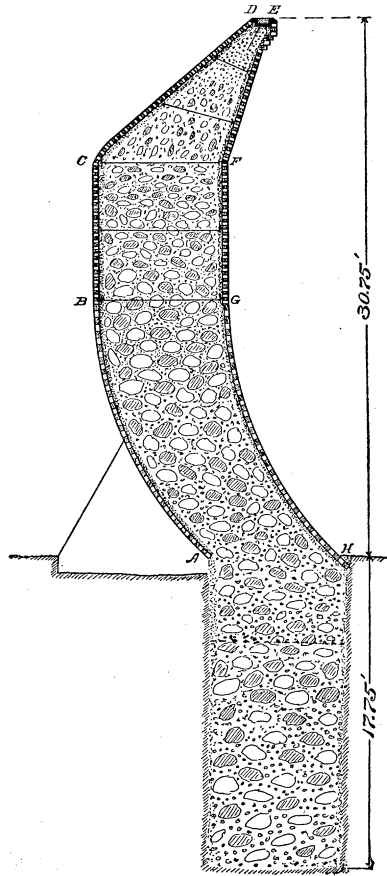


Fig. 119.—View of a Dam at Ithaca, N. Y.

that confidence may be strengthened in the value of concrete for structures placed under trying conditions.

The Ithaca Water Works Company wished to increase and develop their source of supply for the city of Ithaca but felt that they could not put in sufficient capital to build a large dam with a gravity section. Several plans and estimates were made but all were too high in price.



Vertical Section on Center Line.

Fig. 119a.—Cross Section of the Ithaca Dam.

Mr. Gardner S. Williams, Associate Professor of Civil Engineering at Cornell University, was engaged as consulting engineer to prepare plans and he designed the dam illustrated in figures 119 and 119a, accomplishing a reasonably large storage for a minimum construction. The dam was originally designed to be 90 feet high but was reduced to its present height in building. It is built in a narrow slate or shale gorge about 90 feet wide at the point where the

dam is located. The dam is built of concrete reinforced at the face and back with 3 by 3-16 inch longitudinal steel bands spaced 4 feet apart and interlaced with wire mesh.

Five-eighth inch tie rods connect the two systems of reinforcement. Both back and face of dam are faced with vitrified brick or block. The dam is about $7\frac{1}{2}$ or 8 feet thick and is built in a partial dome shape, convex side upstream. The radius of the horizontal curvature is 100 feet.

During construction it successfully withstood a severe overtopping flood. Messrs. Ross F. Tucker and Thomas M. Vinton built the dam.

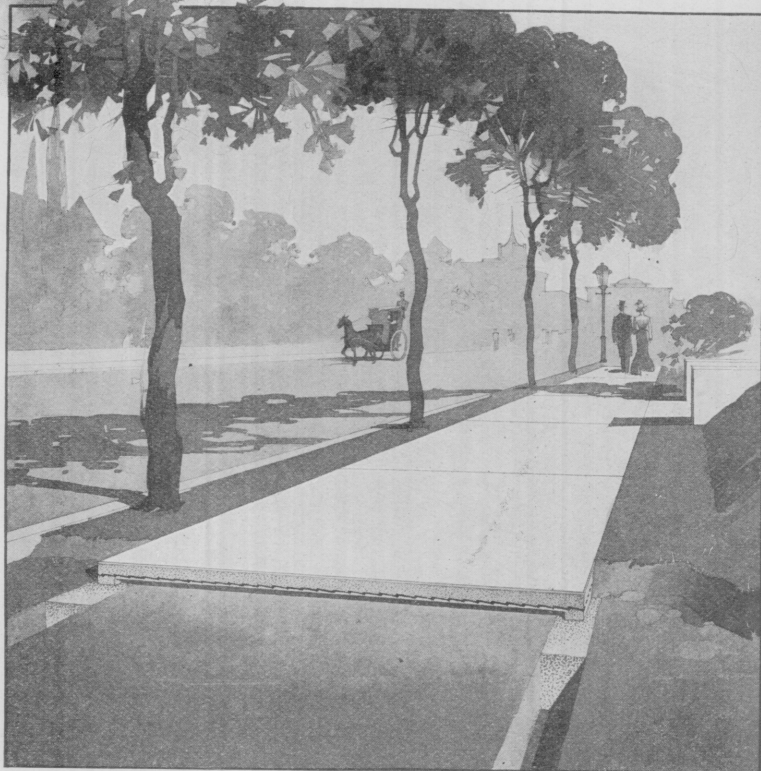


Fig. 120.—Sidewalk Composed of Reinforced Concrete Slabs, According to the St. Louis Expanded Metal Company's System.

METALLOID SIDEWALKS.

The St. Louis Expanded Metal Company have a new design for sidewalks which would seem to have some commendable features. By the use of sheets of expanded metal, concrete sidewalk blocks five or six feet square and about 2 inches thick are made at some central factory, and the blocks are then shipped to the site ready to set in place like stone slabs.

The foundation consists of two trenches filled with cinders upon which the concrete stringers at the edges of the slabs rest. The center portion of the block does not rest upon the ground, hence is not affected by the heaving due to frost.

It is claimed that this form is no more expensive than the usual concrete walk and it can be laid at any season of the year, without interrupting traffic. Figure 120 illustrates the method.

FIRE PROOFING, FIRE TESTS AND FIRES.

The fire proof qualities of concrete and concrete-steel are becoming better known each year. Theoretically, a good fire proofing material must have two qualities, it must be able to resist sudden changes of temperature within its own structure without disintegration and it must be a non-conductor of heat. The porous nature of concrete, and especially of cinder concrete, prevents heat from rapidly penetrating the mass. A comparatively small section of cinder concrete will prevent the temperature of enclosed steel from becoming high enough to destroy its strength or to badly expand or warp it. Tests seem to prove that concrete has both of the desirable qualities.

Mr. E. Lee Heidenreich, the agent for the Monier system in the United States, says he has heated Monier plates 2 inches thick, one foot wide and three feet long to a temperature of 1,200 degrees, Fahrenheit, and cooled them off by plunging them into cold water without showing any deteriorating effect. This would indicate not only that the concrete could successfully resist great sudden changes in temperature, but also that the coefficient of contraction and expansion of concrete and steel are nearly similar. For if this were not true, the variation of expansion and contraction of the metal in the plate would have ruptured the concrete. The test mentioned in the description of the Roebling system of reinforced concrete also bears witness to the power of concrete to resist the destructive effects of fire.

New York City Fire Tests.—In 1901,* the Department of Buildings of New York City conducted a series of fire tests quite severe in character, which nearly every firm in the tests, using Portland cement in any form, successfully passed. The department specified the

**Engineering News* December 26, 1901.

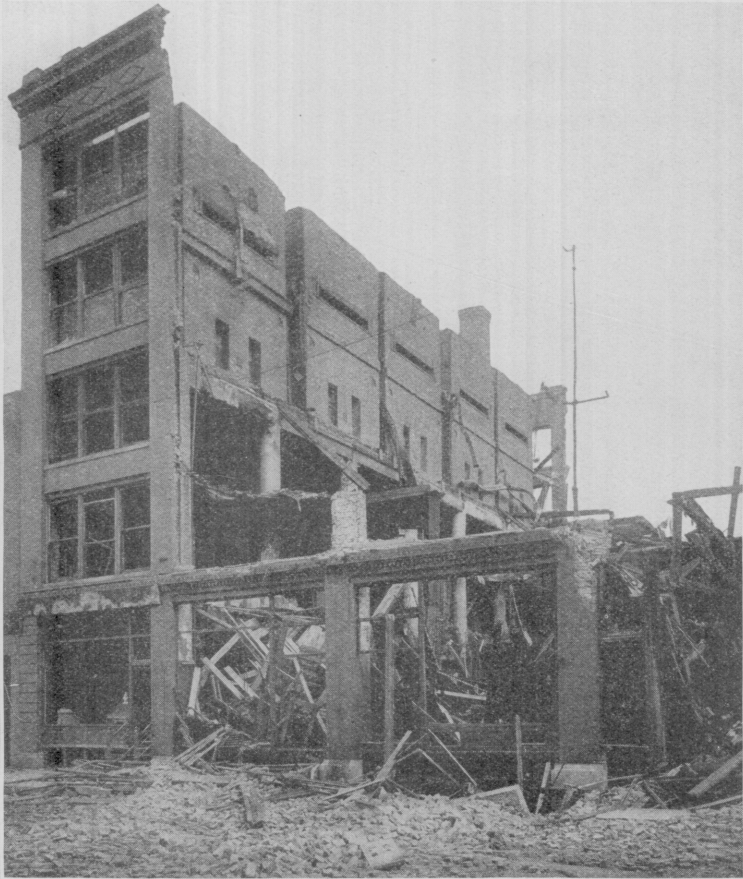


Fig. 121.—Ruins of the McMahon Cracker & Biscuit Company's Building, Burned October 8th, 1901, at Chicago, Ill. Only the Armored Concrete Work Remains Intact.

method of procedure, the size and shape of the house to be constructed and the arrangement to be made for firing.

The partitions and test walls were erected by the firm interested in the particular fire proofing submitted for test.

The houses were all $9\frac{1}{2}$ by $14\frac{1}{2}$ by 12 feet high. The test walls were from 2 to 4 inches thick. The houses were built with a flue in each corner to provide for thorough circulation and quick heating. Grates were built 3 feet above the foundations and heavy protected doors were provided so that access was given for firing and observations. Kerosene, pine and hard wood were used for fuel. The temperatures were to be kept from 1,700 degrees to 2,100 degrees, Fahrenheit, for one hour and then water from the city mains was to be thrown on to the heated walls for $2\frac{1}{2}$ minutes through fire nozzles with the regular city pressure.

The test that is of particular interest here was the one made upon the Sprickerhoff partition. This partition was built of concrete blocks 3 inches thick plastered one-half inch thick on both sides with King's Windsor "browning mortar." The blocks were composed of 1 part Portland cement, 1 part sand, and 5 parts steam ashes—the blocks being laid in a cement mortar of 1 cement to 2 sand. The temperature reached 1,868 degrees, Fahrenheit. Water was applied which stripped the plaster, but left the concrete portion unharmed and as straight and plumb as before the test.

There is nothing so convincing, however, as the actual test upon buildings in service.

McMahon Cracker and Biscuit Company's Building.—The building of the McMahon Cracker Company, located in Chicago, burned on October 8, 1901. The entire structure was totally wrecked, except the portion holding five large bake ovens, each weighing 200 tons. These were situated from the third to the fifth floors and were supported by steel columns protected by a concrete shell composed of 1 part Louisville natural cement and 4 parts soft coal cinders, enclosed in a wire form plastered with cement mortar on the outside. The steel work in the other portion of the building was twisted and ruined and the walls, left unsupported, fell. But the heaviest portion of the building supported by concrete protected steel remained standing. Figure 121 shows the results of the fire.

The Borax Company's Building.—The Pacific Coast Borax Company's building situated at Bayonne, N. J., was destroyed by fire, April 11, 1902. A large portion of the main building—the footings, walls, posts, girders, floors and a few partitions—were of steel concrete. The floors were concrete slabs 4 to 5 inches thick resting on and being monolithic with concrete beams, which were $4\frac{1}{2}$ inches

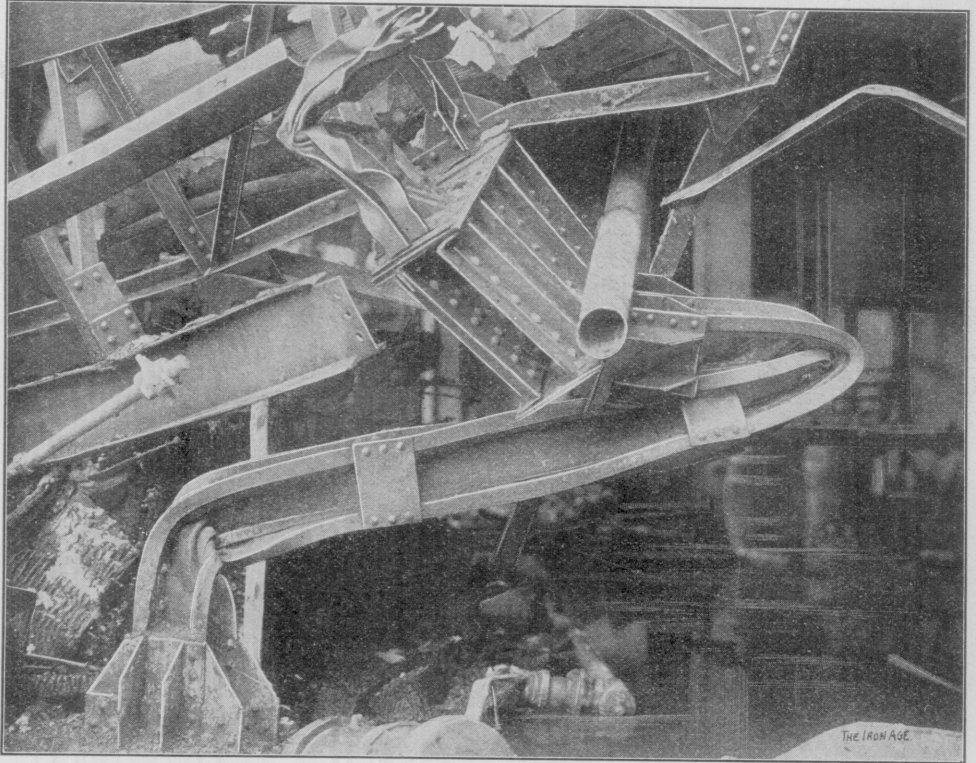


Fig. 122.—The Effect of Fire on Steel Construction. The Pacific Coast Borax Company's Works, Bayonne, N. J.

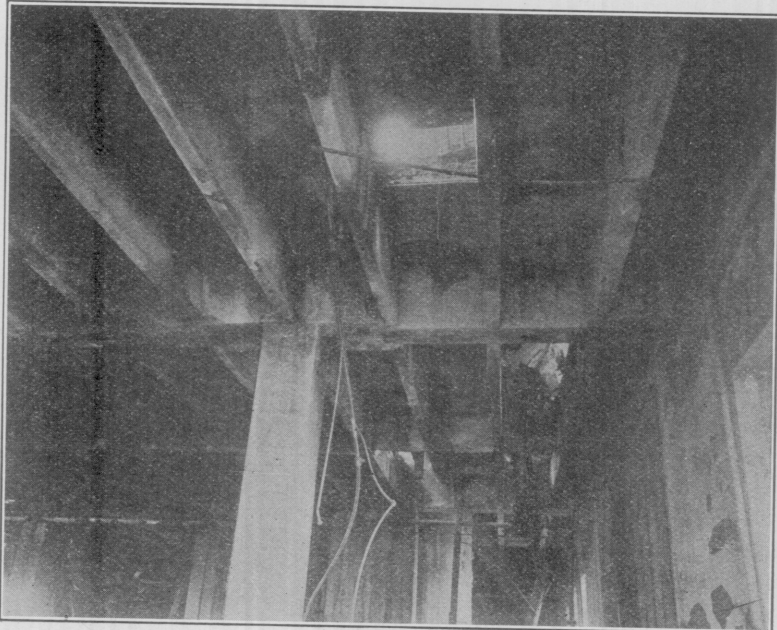


Fig. 123.—Effect of Fire on Reinforced Concrete Construction, Pacific Coast Borax Company's Works. The Fire was Exceptionally Hot at This Point.

wide, 28 inches deep and 24 feet long, spaced 3 feet center to center. The columns were of solid Ransome steel concrete, being 21, 19 and 17 inches square for the first, second and third stories, respectively. The walls were 16 inches thick, having 9 inch hollow spaces in the center. The concrete was made of Atlas Portland cement and crusher run of basaltic rock passing a 1 inch ring screen. No sand was used, the fine crushed basalt taking its place. The proportions varied in different portions of the work from 1 part cement and 5 crushed stone to 1 cement and $6\frac{1}{2}$ stone.

One wing where the crystallizing tanks were placed was of steel frames with wooden walls, partitions and fixtures. Much inflammable material was stored all through the building at the time. The roof was of wooden beams and light supports, with board and tar covering. There were many wooden partitions in the main building, much wooden framing for the shafts, machinery supports, stairways and bins.

The heat of the fire was sufficient to fuse copper in several places in the building. All steel posts and girders were warped out of all semblance to their proper shape. Several large tanks set upon the roof, one a concrete tank 6 by 6 feet and 50 feet long, weighing 33 tons, fell through to the fourth floor without doing any injury. The clear fall from roof to floor was 14 feet. One steel tank weighing 18 tons fell corner-wise, apparently, and that cracked two or three concrete floor girders and broke a small hole through the floor. With the exception of the cracked floor beams, no damage was done to the concrete portion of the building except to crack off the plaster here and there and to smoke up the walls and ceilings so that a coat of paint or plaster was required to put them in presentable shape.

The floors held three and four inches of water after the fire without showing any leakage.

Figure 122 shows the results of the fire in the one story portion of the building where there was not a great amount of combustible material. Figure 123 shows the condition of the concrete at the point where the fire was the most intense and where the hole was punched in the floor doing the greatest damage.

The test was so conclusively in favor of concrete for a fire proof material that the company in rebuilding made all of their partitions, the roof, bins and the machinery and shafting supports out of concrete.

The writer visited the works on August 28, 1902, just before the rebuilding was completed; the plant had been in operation, however, for some months, as it took but little work to get the main building in condition to operate the plant. The work in progress was the laying of the roof.

In making the roof, planed boards were used for the forms. They were carefully put up and thoroughly supported. A thin coat

of white plaster one-half inch or less in thickness, apparently carrying some plaster of Paris, was spread upon the forms and then the iron bars and concrete were put in place. The white mortar acted as a plaster or surface coat for the underside of the roof.

Within the building heavy machinery, crushers, filter presses, tanks, etc., were set upon the floor or hung from the ceiling with no extra strengthening attempted. Borax, weighing 340 pounds per barrel, was stacked three barrels high over large areas. In fact, much of the floor, so the general manager said, had been tested in actual service by loads of 1,000 to 1,650 pounds per square foot.

Baltimore Fire.—The Engineering News* employed several experts to investigate and report upon the fire proof construction within the area swept by the great Baltimore fire of February 7, 1904. Extracts from these various papers read: "Comparing the efficiency of concrete and the hollow blocks as fire-proofing materials, there is no doubt but that the concrete made from steam boiler cinders and Portland cement, made the best showing."

"Generally speaking concrete and terra cotta protected successfully the steel columns."

"As fire and water resisting materials, terra cotta and concrete have given a very good account of themselves."

"The buildings were all gutted, but the concrete floors were all apparently in first-class condition. The iron work was not exposed and the concrete did not appear to be disintegrated."

"The concrete construction† (speaking of the Fidelity and Guaranty Company's building) endured the fire practically uninjured, a notable demonstration being the fact that the cantilever extensions of the floors in front and rear remained intact, and the attic floor carried a tier of columns reaching to the roof which it had never been designed to support."

"In a few cases where the heat was the greatest, fine surface cracks were seen in the beams and ceilings and small portions of the concrete had flaked off, but nowhere sufficient to indicate serious injury to the structure."

One of the floors in this building was afterward tested by loading it with a uniformly distributed load of 225 lbs. per square foot and it only showed 1-16 inch deflection under the load. The concrete used in the United States Fidelity and Guaranty Company's building was composed of 1 cement, 3 sand and 5 crushed granite. Two other buildings were of so called fire proof construction.

**Engineering News* March 3, 1904.

†*Engineering Record* March 18, 1904

CHAPTER V.

SPECIFICATIONS FOR CONCRETE MATERIALS.

In the following pages the effort has been made to show what safeguards may be thrown around the use of cement for the numerous class of structures which have been described in the foregoing chapters. It will be, of course, understood, that the framing of specifications for a piece of work of great importance where either large sums of money or human life is involved in any failure of the structure as in dams, bridges, floors, etc., is a work which properly belongs to the trained engineer and to him alone. Each piece of work of this sort must be made a special study and take into consideration all the local and unusual features of the case as well as considerations based on the normal qualities of the materials.

But there are a very large class of uses of less importance, where no such results depend, and there is no reason why the architect, contractor, builder, owner and in fact any person of intelligence, but devoid of engineering training, may not with safety and satisfaction to himself, prescribe the conditions under which the cement structure shall be built.

Accordingly a number of specification forms which have been prepared by skilled engineers and cement users, are here reproduced in order to serve as models upon which others may draw their contracts.

CEMENT.

The cement may be of any brand of American or foreign Portland cement which will meet the requirements of these specifications.

Condition of Delivery.—It must be delivered in original packages labeled with the brand and the name of the manufacturer. These packages may be either barrels or bags, but must be well protected in either case from air and moisture. Any broken packages may be rejected or used at the option of the engineer in charge of the work.

Time of Delivery.—The contractor shall furnish the cement upon the work at least ten days before it is to be used, in order that time may be given to make the necessary tests.

Housing.—It shall be stored in dry, well ventilated buildings for work of any magnitude; and for work of less importance it shall be safely stored and protected from moisture in any form.

TESTS OF PORTLAND CEMENT.

The cement shall stand the following tests; any that fails to meet these tests will be rejected and the contractor shall immediately remove the same from the work.

Soundness. —Two pats of neat cement, with thin edges, will be made upon glass plates, and allowed to attain permanent set in moist air. Twenty-four hours after making, one pat will be placed in water having a temperature between 50 and 70 degrees F., and must withstand indefinite exposure without checking, softening or distortion. The other pat will be placed in some form of a steamer over cold water, which shall be brought to the boiling point and maintained at this temperature for three hours and then allowed to cool slowly. The pat shall not show any signs of distortion, cracking or softening under this test.

Fineness. —The cement shall be so finely ground that after being thoroughly dried by heating it 94 per cent. shall pass through a No. 100 standard sieve, woven from No. 40 Stub's wire gauge.

Activity. —Initial set shall not occur in less than 40 minutes, and final set in less than one hour and 30 minutes nor more than six hours. The time of setting shall be determined by Gilmore's wires, or Vicat's needle.

Tensile Strength. —The standard section of briquette shall be used. The neat cement shall be mixed into a rather dry, stiff paste by the addition of from 17 to 20 per cent. of its weight of water. In a mortar of sand and cement, water to the amount of 10 to 13 per cent. of their combined weights shall be used, the amount depending upon the character of the cement and sand. The mortar shall be firmly pressed into the molds with the thumbs, filling the molds in three layers of about equal thickness and smoothing off both sides with a trowel. Briquettes shall remain in moist air for twenty-four hours and the remainder of the time, until tested, they shall remain in water at a temperature of about 60 to 65 degrees F.

Seven day tests of neat cement shall show not less than 450 pounds per square inch, and not less than 550 pounds for 28 day tests. Briquettes made of 1 part cement to 3 parts standard sand shall stand a test of 150 pounds per square inch at seven days.

SPECIFICATIONS FOR SAND.

All sand used for mortar shall pass a No. 10 sieve and 80 per cent. of it shall be retained upon a No. 74 sieve. It shall be a silicious sand, as sharp as can be obtained within reasonable limits of cost. It shall be free from all vegetable and organic matter, and shall not contain more than 10 per cent. by weight, of clayey or loamy material.

SPECIFICATIONS FOR STONE.

The aggregate shall consist of crushed trap rock, granite, hard limestone, or other material equally hard and durable which shall meet the approval of the engineer. The broken stone shall be free from vegetable or organic matter in any shape and free from mud and dust or from lumps of clay or clay covered fragments. When sand is to be used in the concrete, the stone shall be screened to pass through a (—) inch ring and retained by a screen of $\frac{1}{4}$ inch rings. The stone should be thoroughly wet before mixing with the mortar. When it is desired to use screenings with the crushed stone, the proper proportion of sand to be used shall be determined by analysis.

SPECIFICATIONS FOR CONCRETE.

Proportions.—The concrete shall consist of one part cement, 2 to 4 parts of sand, and 4 to 10 parts of crushed stone measured by loose volume. (The proportions must vary to suit the character of the work and the requirements which the concrete must meet.)

Mixing.—The sand and cement shall be thoroughly mixed dry, then sufficient water added to make a plastic or wet mortar and the whole thoroughly mixed again. The stone, having been previously wet down, shall then be added and the whole mass thoroughly mixed until every particle of stone is coated with mortar. The concrete thus mixed should be immediately placed in position and rammed until excess mortar shows over the entire surface. (Where surfaces are to be exposed, either a facing of 1 cement to 2 sand shall be used and placed in position as the mass of concrete advances, or else the stone should be forced back by thrusting down flat bladed shovels along the face of the form, thus allowing the richer mortar to run in next the form which makes a smooth impervious surface.) No concrete which has attained partial set shall be used. The engineer will be guided by the tests in establishing a limit of time beyond which any concrete once mixed shall not be used in the work.

SPECIFICATIONS FOR PORTLAND AND NATURAL CEMENT.

Adopted May, 1903, by the American Railway Engineering and Maintenance of Way Association.

PORTLAND CEMENT.

1. **Definition.**—Portland cement is a product of the mixture of clay and lime-carbonate in definite proportions, calcinated at a high temperature and reduced to a fine powder.

2. **Packages.**—Cement shall be packed in well-made wooden barrels lined with paper, or in strong cotton or paper sacks. Each package shall be plainly marked with the brand and name of the manufacturer, and the net weights shall be exact and uniform.

3. **Weight.**—One barrel shall contain not less than 376 pounds of cement, and four sacks shall be equivalent in weight to one barrel.

4. **Condition.**—All cement shall be delivered in sound packages, undamaged by moisture or other causes.

5. **Storage.**—Cement must be stored until used in a perfectly dry place in such manner as will insure it from all damage.

6. **Rejection.**—All cement failing to meet the requirements of the specifications may be rejected, and all rejected cement, whether damaged or rejected for other causes, shall be removed at once from the company's property.

7. **Tests.**—All cement shall be subject to the following tests:

(1). The selection of the sample for testing, the number of packages sampled, and the quantity taken from each package, must be left to the discretion of the engineer, but each sample should be a fair average of the contents of the package from which it is taken. At least one barrel in every ten should be sampled.

(2) Cement in barrels should be sampled through a hole made in the center of one of the staves, midway between the heads, or in the head, by means of an auger or sampling iron similar to that used by sugar inspectors. If in bags, it should be taken from surface to center.

(3) All samples should be passed through a sieve having twenty meshes per linear inch in order to break up lumps and remove foreign material. For determining the characteristics of a carload of cement the individual samples may be mixed and the average tested; where time will permit, however, each sample will be tested separately.

8. **Fineness.**—Not less than 94 per cent. of the cement tested shall pass through a No. 100 standard sieve. The standard sieve shall be circular, about 20 cm. (7.87 ins.) in diameter, 6 cm. (2.36 ins.) high, and provided with a pan 5 cm. (1.97 ins.) deep and a cover. The wire cloth in the sieve to be woven (not twilled) from brass wire having a diameter of 0.0045 ins. This cloth to be mounted in the frame without distortion; the mesh should be regular in spacing and for a No. 100 sieve shall contain not less than 96 nor more than 100 meshes per linear inch. The cement to be thus tested shall be thoroughly dried at a temperature of 100° C. (212 degrees Fahr.) before sieving.

9. **Set.**—(1) Initial set shall not occur in less than thirty (30) minutes.

(2) Final set shall not occur in less than one hour nor more than ten hours.

(3) The time of setting shall be determined by means of the Vicat needle apparatus as recommended by the Committee of the American Society of Civil Engineers upon uniform tests of cement in conjunction with the Committee of the International Association for Testing Materials.

(4) Using a paste composed of neat cement and water, of normal consistency, the initial set is said to have commenced when the needle ceases to pass a point 5 mm. (0.20-in.) above the upper surface of the glass plate in the Vicat apparatus, and is said to have terminated the moment the needle does not sink visibly into the mass.

(5) The paste is of normal consistency when the cylinder of the Vicat apparatus penetrates to a point in the mass 10 mm. (0.39-in.) below the top of the ring.

(6) The amount of water required to make a paste of normal consistency varies with different cements, but will be found to be approximately 20 per cent. of the weight of the cement. It should have a temperature of 70 degrees Fahrenheit.

10. **Soundness.**—(1) A pat of neat cement $2\frac{1}{2}$ to 3 inches in diameter, $\frac{1}{2}$ -inch thick at center, tapering to a thin edge, and allowed to take its final set in moist air, must withstand indefinite exposure in water or air at any ordinary temperature without checking distortion or softening,

(2) A pat of neat cement as above, placed in water, which shall be slowly raised to the boiling point and then maintained in that condition for three hours and allowed to cool gradually, shall not show any signs of checking, distortion or softening. The same result should follow exposure to steam not under pressure for three hours. This test may or may not be cause for rejection, at the option of the engineer in charge.

11. **Tensile Strength.**—(1) The briquette used in testing shall be formed in molds of the size and form now in customary use and recommended by the American Society of Civil Engineers, the stress to be applied at a uniform rate of 600 pounds per minute until fractured.

(2) All briquettes of neat cement are to be made from paste of normal consistency in the following manner: The molds should be filled with the paste as soon as it is thoroughly mixed and tempered, the material pressed in firmly with the fingers and smoothed off with a trowel without ramming; the material should be heaped up on the upper surface of the mold, and in smoothing off the trowel should be drawn over the mold in such a manner as to exert a moderate pressure upon the excess material. The mold should then be turned over and the operation repeated upon the other side.

(3) Briquettes for twenty-four hours tests shall be allowed to set twenty-four hours in moist air.

(4) Briquettes for seven and twenty-eight day tests shall be allowed to set one day in moist air and remainder of period in water.

(5) All briquettes are to remain in the water until they are placed in the testing machine, except in the case of twenty-four-hour tests.

(6) Neat twenty-four-hour tests shall not show less than 125 pounds per square inch. Neat seven-day tests shall not show less than 400 pounds per square inch. Neat twenty-eight-day tests shall not show less than 500 pounds per square inch, and should show at least 10 per cent. increase above the seven-day test.

12. **Sand Test.**—Owing to insufficient data, the Committee is not prepared to specify a sand test.

13. **Specific Gravity.**—The specific gravity, determined upon dried cement which has passed through a No. 100 sieve, shall not be less than 3.10 nor more than 3.30. The specific gravity can be conveniently and accurately determined by the use of Le Chatelier's apparatus as recommended by the Committee on uniform tests of cements.

14. **Chemical.**—Chemical analyses should show not more than 5 per cent. of magnesia, nor more than 1.75 per cent. of sulphuric anhydride.

15. **Uniformity.**—If in the tests of any given brand of cement any sudden, irregular or wide variation from its normal action is found, it should be withheld from use until more extended tests shall have demonstrated its reliability.

NATURAL CEMENT.

NOTE—Only those sections of the natural cement specifications which differ from those of the Portland cement are printed here. To make these specifications complete, supply the missing numbers from the preceding.

1. **Definition.**—Natural cement is a product formed of calcinated limestone containing clay and carbonate of magnesia reduced to a fine powder.

3. **Weight.**—One barrel shall contain not less than 300 pounds of cement. (West of the Allegheny Mountains this may be 265 pounds.) Three paper sacks or two jute sacks of cement shall be equivalent in weight to one barrel.

8. **Fineness.**—Not less than 80 per cent. of the cement tested shall pass through a No. 100 standard sieve.

9. **Set.** (1) Initial set shall not occur in less than twenty (20) minutes.

(2) Final set shall not occur in less than forty-five (45) minutes nor more than four (4) hours.

(6) The amount of water required to make a paste of normal consistency varies with different cements, but will be found to be approximately 30 per cent. of the weight of the cement. It should have a temperature of 70 degrees Fahrenheit.

11. **Tensile Strength.**—(1) The briquette used in testing shall be formed in molds of the size and form now in customary use and recommended by the American Society of Engineers, the stress to be applied at a uniform rate of 400 pounds per minute until fractured.

(6) Neat twenty-four-hour tests shall not show less than 60 pounds per square inch. Neat seven-day tests shall not show less

than 100 pounds per square inch. Neat twenty-eight-day tests shall not show less than 150 pounds per square inch, nor less than 25 per cent. above the seven-day test.

13. Specific Gravity.—The specific gravity, determined upon dried cement which has passed through a No. 100 sieve, shall not be less than 2.50 nor more than 2.80. The specific gravity can be conveniently and accurately determined by the use of Le Chatelier's apparatus as recommended by the Committee on uniform tests of cements.

PORTLAND CEMENT CONCRETE.

The following Specifications for Concrete were not acted upon by the Convention for lack of time, but are considered of such importance as to justify publication in this form:

Cement.—Cement shall be Portland, either American or foreign, which will meet the requirements of the standard specifications.

Sand.—Sand shall be clean, sharp and coarse, but preferably of grains varying in size. It shall be free from clay, loam, sticks and other impurities.

Stone.—Stone shall be sound, hard and durable, crushed to sizes not exceeding two inches in any direction and freed from dust by screening.

Gravel.—Gravel shall be composed of clean pebbles of hard and durable stone, of sizes not exceeding two inches in diameter, free from clay and other impurities except sand. When containing sand in any considerable quantity, the amount per unit of volume of gravel shall be determined accurately to admit of the proper proportion of sand being maintained in the concrete mixture.

Water.—Water shall be clean and reasonably clear, free from sulphuric acid or strong alkalies.

Mixing by Hand. (1) Tight platforms shall be provided of sufficient size to accommodate men and materials for the progressive and rapid mixing of at least two batches of concrete at the same time. Batches shall not exceed one cubic yard each, and smaller batches are preferable, based upon a multiple of the number of sacks to the barrel.

(2) Spread the sand evenly upon the platform, then the cement upon the sand, and mix thoroughly until of an even color. Add all the water necessary to make a thin mortar and spread again; add the gravel if used, and finally the broken stone, both of which, if dry, should first be thoroughly wet down. Turn the mass with shovels or hoes until thoroughly incorporated and all the gravel and stone is covered with mortar; this will probably require the mass to be turned four times.

(3) Another approved method, which may be permitted at the option of the engineer in charge, is to spread the sand, then the cement, then the gravel or broken stone; add water and mix thoroughly as above.

Mixing by Machine.—A machine mixer shall be used wherever the volume of work will justify the expense of installing the plant. The necessary requirements for the machine will be that a precise and

regular proportioning of materials can be controlled and the product delivered be of the required consistency and thoroughly mixed.

Consistency.—The concrete shall be of such consistency that when dumped in place it will not require much tamping. It shall be spaded down and tamped sufficiently to level off, and will then quake freely, like jelly.

Course.—(1) Each course should be left somewhat rough to insure bonding with the next course above; and if it be already set, shall be thoroughly cleaned and dampened before the next course is placed upon it. The plane of courses shall be as nearly as possible at right angles to the line of pressure.

(2) An uncompleted course shall be left with a vertical joint where the work is stopped.

(3) The work should be carried up in sections of convenient length and completed without intermission.

Expansion Joints.—(1) In exposed work expansion joints shall be provided at intervals of thirty to fifty feet. A temporary vertical form or partition of plank shall be set up and the section behind completed as though it were the end of the structure. The partition will be removed when the next section is begun and the new concrete placed against the old without mortar flushing. Locks shall be provided if directed or called for by the plans.

(2) In reinforced or steel concrete the length of these sections may be materially increased at the option of the engineer.

Time.—Concrete shall be placed immediately after mixing and any having an initial set shall be rejected.

Facing.—About one inch of mortar of the same proportions as used in the concrete may be placed next to the forms, immediately in advance of the concrete, or a shovel facing made, at the option of the engineer in charge.

Forms.—(1) Forms shall be substantial and unyielding, properly braced or tied together by means of wire or rods.

(2) The material used shall be of dressed lumber, secured to the studding or uprights in horizontal lines.

(3) Planking once used in forms shall be cleaned before being used again.

(4) The forms must not be removed within forty-eight hours after all the concrete in that section has been placed. In freezing weather they must remain until the concrete has had a sufficient time to become thoroughly set.

(5) In dry but not freezing weather, the forms shall be drenched with water before the concrete is placed against them.

(6) For backings, undressed lumber may be used for forms.

Finishing.—(1) After the forms are removed, any small cavities or openings in the concrete shall be neatly filled with mortar if necessary. Any ridges due to cracks or joints in the lumber shall be rubbed down; the entire face shall then be washed with a thin grout of the consistency of whitewash, mixed in the proportion of one part of cement to two parts of sand. The wash should be applied with a brush.

(2) The tops of bridge seats, pedestals, copings, wing walls, etc., when not finished with natural stone coping, shall be finished

with a smooth surface composed of one part cement and two parts of granite, or other suitable screenings, or sand applied in a layer 1 to 1½ inches thick. This must be put in place with the last course of concrete.

(3) In arch tops, a thin coat of mortar or grout shall be applied over the top to thoroughly seal the pores.

Proportioning.

STRUCTURE.	PARTS BY VOLUME			
	Cement.	Sand.	Gravel.	Broken Stone.

The proportion of the materials in the concrete shall be as specifically called for by the contract, or as set forth herein, upon the lines left for that purpose; the volume of cement to be based upon the actual cubic contents of one barrel of specified weight.

- H. G. KELLEY, Chief Engineer, Minneapolis & St. Louis Railway, Minneapolis, Minn., *Chairman*;
 W. L. BRECKENRIDGE, Chief Engineer, Chicago, Burlington & Quincy Railroad, Chicago, Ill., *Vice-Chairman*;
 E. C. BROWN, Engineer Maintenance of Way, Union Railroad, Port Perry, Pa.;
 M. W. COOLEY, Consulting Engineer, Boston, Mass.;
 JOHN DEAN, Consulting Engineer, St. Louis, Mo.;
 C. F. W. FELT, Chief Engineer, Gulf, Colorado & Santa Fe Railway, Galveston, Tex.;
 W. E. HOYT, Consulting Engineer, Rochester, N. Y.;
 C. LEWIS, Civil Engineer, New York, N. Y.;
 G. F. SWAIN, Professor of Civil Engineering, Massachusetts Institute of Technology, Boston, Mass.,

Committee.

SPECIFICATIONS FOR CONCRETE SIDEWALKS.

The following represents a good specification form for sidewalk construction as prepared by the writer:

Estimate No.....	No. of Street.....
Ordinance Page.....	No. of Letting.....

SPECIFICATIONS.

For Improving
 From
 To
 With Sidewalk requiring
 approximatelysquare feet.

Requirements.—All sidewalks shall be — feet, — inches (— ft. — in.) in width, the top of said walks when complete to be at the grade established by the engineer, with a slope of one-fourth inch to the foot toward the center of the street. All walks shall be laid with a space of — inches between the inner edge of the walk and the lot line, except by special permit from the (.....).

Proper authority.

Grading.—All cutting and filling necessary to bring the foundation to subgrade, as given by the engineer, must be done by the contractor. Wherever the soil is clay, peat or black mold, it must be removed to a depth of ten and one-half ($10\frac{1}{2}$) inches below the finished grade and cinders, sand or gravel filled in and thoroughly packed, rammed or rolled solid to make a foundation six (6) inches thick. All foundations must be brought to a subgrade four and one-quarter ($4\frac{1}{4}$) inches below finished grade and rammed solid before laying the concrete. Soft and spongy places must be entirely removed and sand filled and rammed in the place.

Concrete.—On the foundation thus prepared shall be spread a layer of concrete, which shall be three and one-half ($3\frac{1}{2}$) inches in thickness, after being thoroughly compacted. The concrete shall be composed of one part of the best quality of Portland cement, two parts clean, coarse, sharp sand, and five parts of broken stones or clean, coarse gravel, of a size not larger than will pass through a $1\frac{1}{2}$ inch ring. The sand and cement shall first be thoroughly mixed dry, then water added and the mortar mixed, after which the stone shall be added and the whole mass again evenly mixed until every particle of stone is completely coated with mortar. The concrete shall be quickly placed in position and thoroughly rammed over its whole surface with an iron shod rammer eight inches square and weighing not less than twenty pounds.

Top Dressing.—Upon this layer of concrete, before it shall have set, shall be spread a finishing coat three-quarter ($\frac{3}{4}$) inch in thickness, composed of one part of the best Portland cement and one and one-half parts torpedo gravel or other gravel satisfactory to the engineer; said

coat to be thoroughly troweled and floated smooth. In both foundation and surface layers of concrete, transverse joints shall be cut at five foot intervals along the walk to allow for expansion and contraction and to more easily provide for any possible settlement or heaving. The surface shall not be dusted with dry cement at any time. Bevel all edges of the blocks. Sprinkle the surface two or three times each day for a week and protect it from the hot sun during the same period.

Drainage.—Where the engineer may think it necessary, the contractor shall lay two or four inch tile drains from the subfoundation to the nearest catchbasin or open ditch, to carry away any water which may collect in the subfoundation.

Cleaning Up.—After the walk has been completed, the contractor shall remove all debris, waste material and excavated earth from the street and leave the parkways in good condition.

The undersigned hereby certifies that he has read the foregoing specifications, and that the proposal for the work is based on the conditions and requirements embodied therein, and should the contract be awarded to him, he agrees to execute the work in strict accordance herewith.

Name

Residence

The following sets of specifications for concrete sidewalk are given here for further comparison with the preceding form.

The specifications in use in Chicago, Ill., are as follows:

CITY OF CHICAGO SPECIFICATIONS FOR CONCRETE SIDEWALKS.

All cutting and filling necessary to bring the foundation to sub-grade, as given by the engineer in charge of the work, must be done by the contractor. When necessary the foundation must be consolidated by wetting, rolling or ramming to give it proper stability. Soft and spongy places not affording a firm foundation must be dug out and re-filled with sand or gravel, and well compacted by ramming, and foundation brought to within four and one-half ($4\frac{1}{2}$) inches of the grade.

On the surface thus prepared shall be placed a layer of hydraulic cement concrete for four (4) inches in thickness, composed of one part best Portland cement, two parts best clean, coarse, sharp sand. After mixing dry, five parts of broken stone, of a size not larger than two and one-half ($2\frac{1}{2}$) inches in dimensions, shall be added and then water added in just sufficient quantity as will give a surplus of moisture when rammed.

The second layer or finishing coat, one-half ($\frac{1}{2}$) inch in thickness, to be made of one part best imported Portland cement and one part torpedo gravel to be used before the first layer has set.

The undersigned hereby certifies that he has read the foregoing specifications, and that his proposal for the work is based on the conditions and requirements embodied therein, and should the contract be awarded to him he agrees to execute the work in strict accordance herewith.

Name

Residence

The specifications in use in Columbus, Ohio, are as follows:

SPECIFICATIONS FOR IMPROVING SIDEWALKS WITH ARTIFICIAL STONE, IN THE CITY OF COLUMBUS, OHIO.

1. By "artificial stone" herein specified is meant a composition of Portland cement, sand, and fragments of natural stone.

2. By "sub-grade" is meant the ground surface upon which the pavement foundation is laid.

3. By "sub-drainage" is meant a line of three (3) inch diameter, round, butt-jointed, hard-burned drain tile, laid in a trench one foot wide and one foot deep below sub-grade, parallel to the direction of the sidewalk, and true for line and grade, the trench to be filled to the sub-grade with broken stone, crushed or screened gravel as herein specified for concrete, which shall be compacted by ramming, care being used not to disturb the drain tile. The out-let or discharge for the drain to be by connection with the street inlets, or, in the absence of street inlets, by such other arrangement as the Engineer may prescribe.

4. By "cinders" is meant clean, sharp, soft coal cinders, free from ashes and clinkers.

5. By "screened gravel" is meant clean sharp bank gravel, free from loam or vegetable matter, so screened that no fragment will measure more than inches on its longest diameter, and not enough of these to make the quantity of fine gravel so small as to prevent its packing readily under the roller. The question as to whether the material is too fine or too coarse, and as to its general suitableness for the purpose for which it is intended, shall rest entirely with the engineer.

6. By "sand" is meant clean, sharp bank sand, free from loam, vegetable matter, or fragments of coal, and screened free from pebbles.

7. By "broken stone" is meant granite, trap-rock, hard limestone, or other hard durable stone, so broken or crushed that no fragment will measure more than one and one-half ($1\frac{1}{2}$) inches on its longest diameter, nor less than one-half ($\frac{1}{2}$) inch on its shortest diameter, to be entirely free from dust or dirt.

8. By "cement" is meant German or American Portland Cement. The cement to be received on the work in unbroken packages, to be fresh, free from lumps, and subject to inspection by the Engineer in every case.

9. By "crushed gravel" is meant clean sharp bank gravel, free from loam or vegetable matter, so broken or crushed that no fragment will measuring more than one and one-half ($1\frac{1}{2}$) inches on its longest diameter.

10. By "paving" is meant the laying of an artificial stone pavement where the sidewalk has not been previously paved with artificial stone.

11. By "repairing" is meant restoring in part artificial stone sidewalks previously laid.

PAVING.

Sub-grade.—The sub-grade will be brought to an even compact surface uniformly twelve (12) inches below the proposed surface of the finished pavement. Soft or spongy earth, vegetable or other perishable matter will be removed, and the space filled with gravel or broken stone thoroughly compacted by ramming.

Sub-drainage.—Sub-drainage will be put in where the Engineer directs.

Foundation.—Upon the sub-grade thus prepared will be spread a bed of cinders, crushed or screened gravel, in sufficient quantity to insure a uniform

depth of eight (8) inches after being compacted by wetting and rolling or ramming, the surface of the cinder, crushed or screened gravel, foundation to be even, parallel to the proposed pavement surface and four (4) inches below it.

Concrete.—Upon the foundation will be placed a layer of concrete. This concrete will be spread and rammed to an even surface, parallel to, and one (1) inch below the proposed pavement surface before any set in the mortar can occur; the concrete must be composed of one (1) part, by measure, of cement, two (2) parts sand, and four (4) parts broken stone, crushed or screened gravel. The cement and sand will be thoroughly mixed dry and then made into mortar with the least possible amount of water. The broken stone, drenched with water, will then be incorporated with the mortar. The concrete will be thoroughly mixed, the mixing to continue until each fragment of stone is completely coated with mortar, spread and rammed until free mortar appears on the surface, which shall be smooth and one (1) inch below the pavement grade. The whole operation of mixing and laying the concrete will be performed as expeditiously as possible by a sufficient number of skilled men. Platforms or boxes will be used in every case for the concrete bed.

Wearing Surface.—The wearing surface will be composed of one (1) part, by measure, of cement, and one (1) part sand, thoroughly mixed dry, with the addition of sufficient clean water to form a stiff mortar. This mortar will be evenly spread upon the concrete base before any set can occur in the mortar and before the concrete has become dry. The mortar, as soon as spread, will be floated and troweled to a true smooth surface at the sidewalk grade, neatly and accurately fitted around all openings or immovable objects in the sidewalk and along the outside margin. Boxes will be used in every case for the mortar bed.

Blocking.—The surface of the pavement, before the mortar sets, will be cut into blocks with a wedge-shaped tool, leaving a clean groove five-eighths ($\frac{5}{8}$) of an inch deep, one-eighth ($\frac{1}{8}$) of an inch wide at the bottom, and one quarter ($\frac{1}{4}$) of an inch at the top, the cut to be finished with a T shaped tool, the object of this being to make firm, smooth, and slightly round the top edges of the groove. The blocks will be made with straight sides, generally rectangular, measuring, ordinarily, not less than four (4) nor more than six (6) feet on a side. The design of the blocking to be subject to special direction by the Engineer in each case. The blocking for driveways will be done by cutting and finishing as before described, except that the grooves will be one-fourth ($\frac{1}{4}$) of an inch at the bottom and one-half of an inch ($\frac{1}{2}$) at the top or pavement surface, the design to be furnished by the Engineer, and will generally be in strips six (6) inches wide across the driveway (along the pavement) or in six (6) inch squares.

Grade of Sidewalk.—The full-width sidewalk, at its junction with the curb, will be, unless otherwise ordered by the Engineer, one-half ($\frac{1}{2}$) inch above the curbing, with a neat bevel and a slight lap. The slope of the full width pavement will be three-eighth ($\frac{3}{8}$) of an inch per foot, up from the curb to the lot line, unless otherwise directed by the Engineer. The alignment, elevation, and slope of pavements less than the full width of the sidewalk will be subject to special direction from the Engineer in each case.

Driveways.—The construction of driveways will be with the same materials and in the same manner as specified for "Paving" except that the gravel or

cinder foundation will be five (5) inches thick, the concrete five (5) inches thick, and the top surface two (2) inches thick.

Repairing.—In repairing, such portions of the existing artificial pavement as ordered by the Engineer shall be removed and new work substituted, laid in precisely the same manner as herein specified under "Paving".

Sidewalk Gutters or Cross Drains.—Only upon special permission by the Engineer will sidewalk gutters or cross drains be allowed.

When surface drains are permitted they will be formed in the artificial stone pavement of such width, depth, and shape as the Engineer specially directs.

Where cross-drains are permitted below the surface they will be laid with vitrified stoneware socket pipe, of such bore as the Engineer directs, with joints cemented with mortar before specified.

All openings in the curbing for outlets into the gutter for cross-drains will be skillfully made by a competent stone cutter, under the direction of the Engineer, and any curbstone defaced or broken in this operation will be replaced.

CEMENT.

Portland Cement must satisfy the following requirements:

1. The cement shall stand a minimum tensile strain of 400 pounds to one square inch section (neat briquettes 1 day in air and 6 days in water.)
2. The cement shall stand a minimum tensile strain of 125 lbs. to one square inch section, 3 parts sand to 1 cement, (1 day in air 6 days in water.)

Natural Cements must stand the following tests:

Neat briquettes must develop after seven days a tensile strain of 100 lbs. per sq. in., 4 weeks 150 lbs. Briquettes made of one part cement and one part sand must stand at the end of seven days a tensile strain of 50 lbs. per sq. in., at the end of 4 weeks 80 lbs. per sq.in.

The specifications in use in Peoria, Ill., are as follows:

SPECIFICATIONS FOR CEMENT WALKS AS USED BY DEPARTMENT OF PUBLIC WORKS, PEORIA, ILLINOIS.

1. **Location.**—The sidewalk herein specified shall be constructed on.....
 Street, in front of Lot.....
 Block of
 Addition.

2. **Width and Slope.**—The walk shall be feet wide, with a transverse slope of one-third of an inch per foot toward the gutter, and shall be laid to the lines and grades given by the City Engineer.

GRADING.

3. **Sub-grade.**—The ground shall be excavated to a depth of twelve (12) inches below the surface of finished walk, and the surface of the sub-grade shall be thoroughly and evenly tamped with an eighty (80) pound tamper.

4. **Excavation.**—In places where cutting is necessary to bring the walk to the required grade, no plow shall be used below a line three (3) inches above the surface to which the sub-grade is to be graded. The remaining three (3) inches to be carefully dressed off with picks or other hand tools.

5. **Fill.**—Wherever fill is required, it will be made with any suitable material excavated from this improvement. Should such suitable excavated material not be sufficient to make the necessary fills, the Contractor will be required to procure material acceptable to the Engineer. All filling shall be made in uniform layers not to exceed four (4) inches in depth, and each layer shall be thoroughly flooded and rolled, or tamped as may be directed to insure a solid bed.

6. **Removing Soft Materials.**—All mud and other soft or spongy material or any material that cannot be made solid and compact, shall be removed and the places refilled with gravel.

7. **Flooding Sub-grade.**—When considered necessary to procure a compact and solid sub-grade, the ground, before being rolled, shall be thoroughly flooded with water in such a manner as the Engineer may direct.

FOUNDATION.

8. **Cinders or Sand.**—Upon the sub-grade prepared as above will be laid a foundation course eight (8) inches thick of sand or cinders, which shall be flooded and thoroughly rolled or tamped in such a manner as to procure a compact and solid foundation.

9. **Concrete.**—Upon this sand or cinder foundation a concrete foundation three (3) inches thick after being compressed, shall be laid.

10. **Proportions.**—The concrete shall be composed of one (1) part, by bulk, of best imported Portland cement, three (3) parts, by bulk, of clean, sharp sand, and five (5) parts, by bulk, of broken stone or gravel.

11. **Intention of Proportions.**—The proportions herein specified are intended to produce a concrete in which the mortar will fill all the voids, and the proportions will be so adjusted that when rammed in place free mortar will flush to the surface.

MIXING AND SPREADING CONCRETE.

12. **Mixing Sand and Cement.**—The sand and cement shall be thoroughly mixed dry in a tight mortar box and then made into a mortar of the proper consistency and thoroughly worked over with hoes.

13. **Additions of Stone.**—Broken stone or gravel thoroughly cleaned of dirt, drenched with water, but containing no loose water in the heap, shall then be added to the mortar in the proper proportion. The concrete will then be turned and mixed until mortar adheres to each fragment.

14. **Consistency of Concrete.**—The concrete thus mixed shall have such a consistency that when rammed the mass will not shake like jelly, but will, when struck, compact within the area of the face of the rammer without displacing the material laterally.

15. **Immediate Use of.**—The concrete thus prepared shall be immediately placed in the work. It shall be spread and thoroughly compacted by ramming until free mortar appears on the surface.

16. **Mixing and Laying.**—The whole operation of mixing and laying each batch of concrete shall be performed in an expeditious and workmanlike manner, and be thoroughly completed before the cement has begun to set.

17. **Re-tempering.**—No re-tempering of concrete will be permitted, and concrete in which the mortar has begun to set will be rejected.

18. **Conform to Grade.**—The upper surface of the concrete shall be made to conform perfectly to the grade of the sidewalk to be laid.

19. **Minimum Temperature.**—No concrete shall be laid when the temperature at any time during the day or night falls below thirty-five (35) degrees Fahrenheit.

WEARING SURFACE.

20. **Composition.**—Upon the concrete base there shall be spread a finish coat, or wearing surface, one (1) inch thick composed of one (1) part cement, $\frac{1}{4}$ of one part crushed quartzite rock, and $\frac{1}{4}$ of one part clean, sharp sand.

21. **Spreading.**—This wearing surface shall be placed on the concrete as soon as the same is tamped and before it has begun to set. It must be quickly and evenly spread, and will then be floated and troweled to a true smooth surface conforming to the grade given.

22. **Blocking.**—The surface of the sidewalk before the mortar sets will be cut into blocks, with a wedge-shaped tool, leaving a clean groove one-half an inch deep, one-eighth of an inch wide at the bottom, and one-quarter of an inch wide at the top. The blocks will be rectangular in shape, with straight sides, measuring not less than four nor more than six feet on a side.

23. **Walk at Curbing.**—When the walk extends to the curb line it shall be one-half ($\frac{1}{2}$) inch above the curbing for the full width, unless otherwise ordered by the Engineer, with a neat bevel and a slight lap at its junction with the curbing.

REQUIREMENTS OF MATERIALS.

CEMENT.

24. **Kind.**—All cement used shall be the best imported Portland cement. It will be subjected to rigid inspection, and that rejected shall be immediately removed by the Contractor.

25. **Cement for Inspection and Tests.**—The contractor must submit the cement for inspection and testing at least ten (10) days before using, and such inspection and tests will be made only from samples obtained by the Inspector from cement delivered on the work. The inspector shall be notified of each delivery of cement. All cement must stand the following tests:

26. **Checking and Cracking.**—Two cakes, three inches in diameter and one-half inch thick, with thin edges, will be made. One of these cakes as soon as set will be placed in water and examined from day to day. If the cake exhibits checks, cracks or contortions, the cement will be rejected. The other cake described will be used for setting and color tests.

27. **Beginning of Set.**—The time will be noted when the cake has become hard enough to sustain a wire one-twelfth inch in diameter loaded with one-fourth pound. When the wire is sustained, the cement has begun to set, and this time shall not be less than forty-five (45) minutes.

28. **End of Set.**—When the cake will sustain a wire one twenty-fourth inch in diameter loaded with one pound, the set is complete, and this time must not be less than two (2) hours nor more than six (6) hours.

29. **Color.**—The cake used for setting test will be preserved, and when examined from day to day must be of uniform color, exhibiting no blotches or discolorations.

30. **Fineness.**—The cement must be evenly ground, and when tested with the following standard sieves, must pass at least the following percentages. No. 50 sieve, having 50 meshes per lineal inch, 98 per cent; No. 74 sieve, having 74 meshes per lineal inch, 94 per cent; No. 100 sieve, having 100 meshes per lineal inch, 90 per cent. The diameter of wire for the sieves being respectively: For No. 50 sieve, No. 35 Stub's wire gauge; For No. 74 sieve, No. 37 Stub's wire gauge; For No. 100 sieve, No. 40, Stub's wire gauge.

31. **Mixing Test Cement.**—All cement for test briquettes, will be mixed with barely sufficient water to make a stiff mortar. The neat briquettes to be pressed into the molds by hand and the sand briquettes to be compacted by light tapping.

32. **Strength.**—The required tensile strength per square inch shall be as follows:

Neat cement:

One day—till set in air, remainder time in water..... 150 lbs.

One week—one day in air, six days in water400 lbs.

Cement one part, and sand three parts:

One week—one day in air, six days in water..... 140 lbs.

33. **Covering Briquettes.**—Briquettes for seven (7) day tests will be covered for the first twenty-four (24) hours with a damp cloth.

SAND.

34. **Sand for Concrete.**—The sand for concrete shall be clean, sharp silicious sand. It shall be free from clay or other mineral impurities, loam or organic matter, and shall be thoroughly screened.

35. **Sand for Finish Coat.**—The sand for cement tests, and for the finish coat of the walk, will be crushed quartzite of such fineness that all will pass a sieve of 10 meshes per lineal inch, and none of it a sieve of 50 meshes per lineal inch.

WATER.

36. **Requirements.**—All water must be practically clean and pure.

STONE.

37. **Quality.**—The stone for concrete shall be of such hardness and durability as shall meet the approval of the Commissioner and Engineer.

38. **Platforms for Stone.**—The broken stone when delivered along the line of work shall be deposited on platforms for that purpose.

39. **Size.**—The broken stone shall range in size from one-fourth ($\frac{1}{4}$) of an inch, to one and one-half ($1\frac{1}{2}$) inches in the greatest dimension. It shall be free from mud, dirt, dust, loam or other objectionable material.

39. **Screening.**—The broken stone shall be screened, when necessary, on a one-fourth ($\frac{1}{4}$) inch screen, to eliminate all dust and small particles, and shall be thoroughly drenched with water immediately before being used in the concrete.

GRAVEL.

40. **Size.**—The gravel shall consist of particles ranging in size from one-fourth ($\frac{1}{4}$) of an inch to one (1) inch in the greatest dimension.

41. **Washed and Screened.**—It shall be clean washed gravel free from loam, vegetable matter, clay, silty sand or other foreign matter and shall be screened on a one-fourth ($\frac{1}{4}$) inch screen.

42. **Platforms for Gravel.**—When delivered along the line of the work, the gravel shall be deposited on platforms made for that purpose.

CINDERS.

43. **Requirements.**—The cinders shall be clean, sharp, soft-coal cinders free from ashes and clinkers.

SPECIFICATIONS FOR HEAVY CONCRETE.

For heavy concrete work, the specifications of Major W. L. Marshall, corps of engineers, for the locks in the Illinois and Mississippi canal in Illinois will serve as a fair example of United States Engineers' practice. Sections II and III only are quoted as being directly applicable to the concrete work.

II. PROPORTIONS AND MIXING OF CONCRETE.

II. Proportions and ingredients are measured by volume, and the number of cubic feet given below represent the quantities to be used for each charge of concrete put into the mixer,

Portland cement concrete shall in general consist of:

Portland cement	1 part=5 cu. ft.=5 sacks
Gravel	4 parts=20 cu. ft.
Broken stone	4 parts=20 cu. ft.

For the wall supporting the upper gate and in the vicinity of the quoins the concrete shall consist of:

Portland cement	6 cu. ft.=6 sacks
Gravel	20 cu. ft.
Broken stone	20 cu. ft.

Natural cement concrete shall consist of:

Natural cement	2 parts=8 cu. ft.=4 sacks
Gravel	5 parts=20 cu. ft.
Broken stone	5 parts=20 cu. ft.

Facing material shall consist of, by volume:

Portland cement	1 part
Torpedo sand passing No. 5 sieve.....	3 parts

12. The piles of gravel and broken stone shall be kept thoroughly sprinkled with water to clean surface of dust and to prevent absorption by the dry stone of the water used in mixing the concrete.

13. When delivered in bags each bag of cement shall be emptied directly into the charging box, as the division of a barrel of cement into several bags diminishes the chances of injurious effect of a defective barrel, and hence the usual requirements of drawing charges from a mixture of five or more barrels may be dispensed with. When delivered in barrels this latter requirement will be observed.

14. All bags and sacks shall be carefully preserved for return to the dealers furnishing cement, in order to secure to the United States the rebate thereon, to be deducted from subsequent bills for cement.

15. The proper measures of ingredients shall be emptied into the charging box in the following order: 1st, gravel; 2nd, cement; 3rd, broken stone; 4th, water.

16. Enough water shall be added to make the concrete cohere after a thorough mixing. A greater degree of plasticity than that possessed by damp sand is required and the object is to have the consistency such that a thorough ramming will bring water to the surface. The mass of concrete should not quake on ramming; incipient quaking marks the limit, and any excess of water in one charge may be corrected by making the next charge a little dryer. The proper amount of water can be determined only by exper-

ience, and must be varied from time to time to suit the conditions of the weather and the ingredients. It is very important that Portland cement shall have sufficient water for its complete hydration. Natural cement requires less water for hydration than Portland.

17. The contents of the charging box shall be dumped immediately into the cubical mixer, which shall be revolved for not less than two minutes at a rate not exceeding nine revolutions per minute. The product is improved by longer mixing, and all the time less than period required for initial set, available between deliveries required at the forms should be utilized for extra turns to the mixer. The facing material shall be mixed by hand, and a very small gang will be able to keep the forms supplied, as for a facing of a uniform thickness of two inches, about 70 cubic yards only will be required for a lock, or about $3\frac{1}{2}$ cubic yards to each section. A close watch must be kept of the quantity used, and the above limit must not be exceeded.

III. DEPOSITING AND RAMMING CONCRETE.

18. Each lock wall shall be built in sections, averaging about 20 feet in length, making 10 sections to each wall. The planes of division between sections shall be at right angles to the axis of the lock, and are indicated on drawings furnished from this office.

19. Each section shall be a monolithic mass of concrete built continuously from the bottom to completion without horizontal joints. The sections shall be filled with horizontal layers about six inches thick, each layer to be deposited before the "initial" set of the previously deposited layer.

20. The vertical planes of division between sections shall be made by transverse bulkheads built in the forms and at each bulkhead a dovetail or recess shall be made for the interlocking of adjacent sections, the dovetails reaching from foundation to one foot below the coping of the sections.

21. Alternate sections shall be built first, then the bulkheads shall be removed and the remaining sections filled with concrete.

22. Before beginning a section, its foundation shall be swept clean with wire brooms and covered with a wet layer one inch thick of 1 to 1 cement mortar to make a close joint between the wall and the foundation.

23. The walls of the wooden forms shall be kept well wet during the progress of the concrete work to prevent their absorption of water from the newly placed concrete.

24. The lowest step or thickest part of the lock walls shall consist of not less than two (2) feet of Portland cement concrete next to the face of the wall and a backing of Natural cement concrete. All other walls or parts of walls shall be of Portland cement concrete.

25. The exposed faces and copings of all walls shall consist of Portland cement and torpedo sand 1 to 3. The thickness of facings shall not exceed $1\frac{1}{2}$ inches, nor be less than $\frac{3}{4}$ inch.

26. The facing and backing must go on simultaneously in the same horizontal layers. In order to gauge the thickness of the facing accurately, a light board or diaphragm of thin metal with convenient handles shall be set on edge parallel to and $1\frac{1}{2}$ inches from the front wall of the forms. The facing material shall be deposited in the space between this board and the form. The concrete of the backing shall then be deposited and spread against the back of this board, which may then be withdrawn and the whole mass thoroughly rammed so as to bond the facing and backing by destroying the surface of demarcation between them, but no stone must be forced

nearer to the front wall of the form than $\frac{3}{4}$ inch. No attempt shall be made to secure a definite surface between the Portland and Natural cement concrete in the lowest step of the lock walls, but they shall be thoroughly bonded, blended and interlocked one into the other by long lap or splice joints in every layer deposited.

27. When the top surface of the coping is reached it shall be finished after ramming by cutting off the excess with a straight edge and rubbed smooth and hard with a float by skilled sidewalk finishers. The wet finishing coat shall be of 1 to 3 mortar with torpedo sand, and shall be as thin as possible without exposing the stone or gravel of the concrete below. The coping of lock walls shall be slightly crowned in the center.

28. The facing and coping shall show a smooth dense surface without pits or irregularities. This is most likely to be secured by thorough and systematic ramming.

29. Concrete shall not be laid in water nor exposed to the action of water until thoroughly set. Concrete or mortar shall not be made when the temperature is lower than 35 deg. fahr. in the shade, nor when rain is falling on it. All concrete work shall cease November 20th, and not be resumed before April 1st. Forms and molds must be left in position for not less than four days after concrete is deposited. Freshly deposited concrete shall be protected from the direct rays of the sun and from wind by boards or tarpaulins, and as soon as a section of wall is completed the exposed coping must be covered with a thick layer of sand and the whole mass of wall must be kept sprinkled until the concrete is thoroughly set.

For the construction of the proposed concrete dam in the Scioto river for the water supply system of Columbus, Ohio, the following specifications were prepared by the City Engineer, Mr. Julian Griggs.

SPECIFICATIONS FOR THE SCIOTO RIVER DAM.

37. Concrete.—This will be composed of one part by measure of cement, loose measure, two parts loose sand, not compacted, and four parts of broken stone. All concrete shall be made only in mechanical mixers, either cubical steel or iron boxes, sometimes called malaxators, measuring five feet on the edge, and capable of mixing two-barrel batches of concrete at one time, or continuous rotary mixers of approved design. These mixers will be supplied with independent friction clutches for each mixer, giving independent action. A sufficient number of these must be provided to turn out the average quantity of 200 cubic yards daily, with an engine capable of turning them simultaneously when loaded. The equipment for manufacture of concrete will comprise all that is necessary for storing a sufficient quantity of material and for handling and accurately measuring the same when placed in the mixers. Material will be placed in the mixers in the order directed by the engineer which will in his judgment give best results, the proportion of water being so regulated that the concrete can be thoroughly compacted and will then show merely a film of moisture upon the surface. Each batch of concrete will be given 28 revolutions, or as many as may be required to produce the most thorough mixing, at a rate not exceeding 7 revolutions per minute, not more than two barrels of cement, with the proper proportions of sand and stone, being mixed at one time. Provision for rapid transportation of the concrete must be made so that it shall be in place in the finished work before the initial set commences. For distributing and ramming the concrete in place after delivery, a sufficient force of rammers and shovelers shall be maintained for each mixer in operation to handle the concrete rapidly and ram it thoroughly. All concrete must be thoroughly compacted by ramming in layers not exceeding six inches in thickness before ramming. The rammers will be of iron or steel, with a flat rectangular face six inches square and weighing not less than twenty pounds.

38. Facings.—The exposed surfaces of concrete work shall be faced with a mortar composed of one part of standard Silica cement which shall comply with these specifications in every particular, and two parts of sand, to which shall be added one per cent. by weight each of pulverized alum and potash soap, the soap to be weighed before being dissolved in water and the alum to be thoroughly mixed dry with the cement and sand. The amount of water to be used shall be barely sufficient to flush slightly to the surface after hard ramming.

The facings of this material shall be not less than three inches thick and shall be incorporated with the body concrete in the following manner: As each batch of concrete is placed next the forms a loose plank shall be put next the form of requisite thickness, so that when removed as soon as concrete is placed and lightly tamped the space left may be filled with the facing material, and the whole thoroughly rammed together at one and the same time. This ramming shall be done with such extreme care as to insure the absence of all holes or the bridging of the material, leaving the surface absolutely smooth and uniform when the forms are removed. Necessary deviations from this method may be adopted on the approval of the Chief Engineer.

39. **Large Stone.**—The incorporation into the concrete of clean, hard, sound stones, roughly scabbled and of all sizes that may be conveniently handled over 50 lbs. weight, will be permitted, provided the stones be separated by a minimum thickness of 4 inches of concrete, and be thoroughly imbedded in the concrete on every side. Such stones must be thoroughly scrubbed clean before being placed in the work and shall be wetted immediately before setting in position. At least 30 per cent. of the entire mass may consist of stones so embodied in the work. Any stones considered unsound or unsuitable by the engineer shall be immediately removed.

40. **Ramming.**—The rammers for the facing shall be of iron or steel with flat rectangular faces $1\frac{1}{4}$ inches by 4 inches. They shall be 5 inches long with solid steel handles. The operation of ramming must give a thoroughly compacted dense, artificial stone of high specific gravity. When deficiency of moisture is indicated after ramming is completed, it will be supplied by sprinkling with a fine spray of water. All exposed surfaces of unfinished work will be kept constantly moist by sprinkling at short intervals. For this purpose not less than one large watering pot for each mixer will be kept in constant service, and as many more as may be required.

41. **Water Tank.**—The contractor will be required to provide a tank of 10,000 gallons capacity, at a height of 50 feet above top of dam, keeping the same well filled and connected with hose for the frequent and practically continuous sprinkling of the finished work.

42. **Surface to be Cleaned and Roughened.**—Rock surfaces, and concrete surfaces more than twenty-four hours old, shall be mopped with a mixture of neat Portland cement mortar immediately before the application of a fresh course of concrete, and all surfaces to which mortar or concrete is applied shall be made clean from any dirt, sand, clay or foreign substances and carefully roughened by picking before the application of such mortar or concrete. Under no circumstances will any concrete be laid in water or in freezing weather.

43. **Concrete Forms.**—Concrete forms must be rigidly held in position so as to give accurately the exterior surface required by the plans for the work, being secured against yielding to the operation of ramming. Surfaces of planking forming exterior faces must give the true, plane surface or curved surface required for the walls, and shall be dressed to make the planks of a uniform thickness. The price bid per cubic yard for concrete in place shall include all lumber, timber, bolts and materials used in the forms for the concrete. Also all special molds for ornamental arches, outline of imitation range work on lower faces as shown by the plans and all pick facing to remove mold marks, and give the exterior face of wall the appearance of cyclopean masonry indicated on the drawings.

44. **Cement.**—The contractor will be required to provide a suitable building, heated when necessary, to maintain the proper temperature, for testing cement, and also the necessary labor for handling the barrels or packages and taking the samples for testing purposes. Cement must be on hand for testing in time to complete all tests before the cement is required for use in the work, which shall not be more than ten days. It is to be stored in dry, well ventilated buildings, and protected from deterioration. It may be rejected for such deterioration, after passing the required tests. Cement must be stored by carload lots for ready removal of any lot condemned. It must be stored in strong packages, well lined with paper, so as to be reasonably secure from air and moisture. Each package to be labeled with the name of the

brand and the name of the manufacturer. Any packages broken at the time of delivery may be rejected, or used as half packages at the option of the Engineer.

45. **Weight.**—Ordinarily ten per cent. of the packages in each carload lot will be selected for weighing and testing. The average net weight of all packages in each carload lot will be the average net weight of all the selected packages. The failure of any one of the selected packages to stand the required tests will be sufficient reason for the rejection of this carload lot, in the discretion of the Engineer. Rejected cement will be branded and immediately removed from the work.

46. **Fineness.**—Of Portland cement, ninety-eight per cent. (98%) by weight must pass through a cement wire sieve having 2,500 meshes per square inch, made of No. 35 wire, S. W. G., and ninety-five per cent. (95%) by weight must pass through a sieve having 10,000 meshes per square inch, and made of No. 40 wire, S. W. G.

47. **Test Briquettes.**—Test briquettes for Portland cement will be made both neat and in proportions of one cement to three of sand. Enough water only will be used to thoroughly moisten the mixture, which will be forced into the mold by pressure or tamping, so as to give as nearly as possible the density of good concrete work. The temperature of the water and of the room in which the briquettes are made and tested will not be permitted to fall below 60 degrees Fahrenheit. The sand used in preparing all briquettes shall be clean, sharp, crushed quartz, retained on a sieve of thirty meshes per lineal inch, (holes 0.022" square) and passing through a sieve of twenty meshes per lineal inch (holes 0.033" square.)

48. **Initial Set and Hot Water Test.**—Cement mixed neat with about 22 per cent. of water to form a stiff paste, shall not begin its initial set for forty minutes after mixing with water and after sixty minutes it must be appreciably indented by the end of a wire one-twelfth inch in diameter, loaded to weigh one-quarter pound. Cement made into thin cakes on glass plates shall not crack, scale nor warp under the following treatment: Three pats will be made and allowed to harden in moist air at from 60 to 70 degrees temperature; one of these will be subjected to water vapor at 176 degrees temperature for three hours, after which it will be immersed in hot water forty-eight hours; another will be placed in water at from 60 to 70 degrees temperature; and the third will be left in moist air.

49. **Tensile Strength.**—The tensile strength will be determined by the average strength of three briquettes of neat cement and the average strength of three briquettes of cement and sand. These will be kept in moist air until set, and then immersed in water until they are put into the clips of the testing machine, being tested wet. Briquettes prepared from neat Portland cement shall, after seven days, develop a tensile strength of not less than 450 pounds per square inch, and after 28 days not less than 550 pounds per square inch. Briquettes prepared from a mixture of one part Portland cement and three parts sand (parts by weight) shall, after seven days, develop a tensile strength of not less than 125 pounds per square inch and not less than 200 pounds per square inch after 28 days. Briquettes prepared from a mixture of one part Portland cement and three parts sand (parts by weight) and immersed, after 24 hours, in water maintained at 170 degrees Fahrenheit, shall not swell nor crack, and shall, after seven days, develop a tensile strength of not less than 150 pounds per square inch.

50. **Sand.**—Sand will be sensibly free from loam, clay, or other impurity, sharp, angular, and silicious. When used in connection with cement tests in the place of standard quartz, it must give results in each case at least equal to those obtained by the use of standard quartz. Samples of the sand proposed to be furnished shall be submitted with each bid and retained in the office of the Department of Public Improvements as a standard for comparison during the progress of the work.

51. **Broken Stone.**—Broken stone for concrete: All of the stone used in the dam must be excavated from the area covered by the site designated by the Engineer, selecting and using only such stone as is hard and durable, of a quality approved by the Engineer, and of such character as to break in approximately cubical fragments. It will be broken so that no dimensions shall be greater than one and one-half inches and must be thoroughly screened from dust and dirt, and washed if deemed necessary.

SPECIFICATIONS FOR CONCRETE ROAD FOUNDATIONS.

In order to give opportunity for comparison, the specifications for concrete foundations under streets and roads for three cities are given.

The specifications in use in Columbus, Ohio, are as follows:

Sec. 28.—CONCRETE ROAD FOUNDATION.

American Portland Cement.—Upon the sub-grade a foundation of American Portland cement concrete shall be laid to a uniform depth of six (6) inches, prepared and applied as hereinafter specified.

Sand.—The sand used in the mortar shall be clean, coarse, screened river or lake sand of approved quality.

Crushed Stone.—The material for the body of the concrete shall be composed of limestone, crushed limestone boulders, or other material, equally hard and approved by the Engineer, broken so as to pass through a two-inch ring in its largest dimensions. The material shall be free from all dust or dirt; no gravel will be used.

Cement.—The cement used will be of the best quality American Portland cement, delivered in original packages, with the brand stamped or printed upon the same.

Fineness.—It must be finely ground, so that at least 90 per cent. will pass through a sieve with 10,000 meshes per square inch.

When mixed with water and worked up into a cake it must not attain its initial set until one hour after mixing, nor its final set until after three hours.

Tensile Strength.—When mixed neat and worked up into briquettes, and exposed one day in air and six days in water, it must develop a tensile strength of 400 pounds per square inch.

When mixed with three parts by weight of standard sand to one of cement, it must develop a tensile strength of 150 pounds per square inch in seven days.

Unsoundness and Color.—Two cakes with thin edges will be made of neat cement, one will be kept under water to note changes of color; the other will be placed in boiling water, after its final set, and kept there for 12 hours; if the color changes in irregular spots during a period of ten days, or if the boiled cake shows any cracks or softness, it shall be rejected as unsound.

Packages to be Marked by Engineer.—All packages of cement must be marked by the Engineer or superintendent before being used.

Mixing.—One part by measure of cement and three parts of sand will be thoroughly mixed dry and then made into mortar with a minimum quantity of water; six parts by measure of crushed boulder, limestone or other equally hard material, having been previously saturated with water, will then be incorporated immediately with the mortar.

Size of Crushed Stone.—Each batch of concrete will be thoroughly mixed, the mixing to be continued on the board until each piece of stone is completely coated with mortar. It will then be spread and at once thoroughly compacted by ramming until free mortar appears upon the surface. The whole operation of mixing and laying each batch will be performed as expeditiously as possible and with the use of a sufficient number of skilled men. The upper surface will be made exactly parallel with the surface of

the pavement to be laid, and when in place all wheeling, working or walking on it must be prevented until it is sufficiently set, and in no case will **any** material be wheeled upon the foundation until 24 hours after having been put in place.

Materials must be brought upon the foundation in barrows, unless delivered upon the same from the sidewalk.

The specifications in use in Washington, D. C., are as follows:

4 **Concrete Base.**—Upon the bed (sub-grade) thus prepared there will be laid a four (4) or six (6) inch foundation of concrete, as directed, made of broken stone and gravel, sand, and natural cement in such proportions that the quantity of gravel will be equal to the volume of voids in the broken stone, and the sand and cement, mixed in the proportion of one (1) part cement and two (2) parts sand, will be 20 per cent. in excess of the volume of voids in the combined gravel and broken stone.

5. **Hydraulic Cement.**—The cement in use shall be a natural hydraulic cement, and shall conform to the current specifications for supplying such hydraulic cement to the Engineer Department of the District of Columbia. No hydraulic cement shall be used upon the work until it has been tested in the office of the Engineer Commissioner and accepted by him, the tests to extend over such length of time, not exceeding twenty-eight days, as the Engineer Commissioner may think necessary. The cement, while in storage or upon the work, while being hauled upon the work, shall be properly protected, and no cement shall be used which, in the opinion of the Engineer Commissioner, has been injured by age or exposure. The cement shall be kept by the contractor in store, under proper cover, in the city of Washington, and subject to inspection for at least ten days before it is used on the streets, and if deemed advisable by the Engineer Commissioner, twenty-eight days. Should the contractor's work be delayed by his failure to keep himself supplied with the necessary amount of approved cement, the District shall have the right to furnish him with tested cement from the stock on hand at its warehouse and charge said contractor with the cost of same at the rate of seventy-five (75) cents per barrel for each and every barrel so furnished, and collect the amount due therefor from any moneys found to be due to said contractor by the District.

6. **Sand.**—The sand used shall be clean, sharp river sand, containing both fine and coarse grains, but free from sewerage, mud, clay, mica, paper, leaves, chips, and other foreign matter, and not showing, when shaken with water and after subsidence, more than five (5) per cent., by volume, of silt.

7. **Broken Stone.**—Stone used in concrete must be hard, durable, and properly broken to a size small enough in their largest dimensions to pass through a ring two (2) inches in diameter, and none smaller than $\frac{1}{2}$ inch can be used. It shall be thoroughly cleansed from all foreign substance and shall be screened and washed, if so ordered by the Engineer. Sand, detritus, or any material other than hard, angular fragments of stone will be considered foreign substances.

8. **Gravel.**—Gravel shall be clean, washed gravel, and shall not contain pebbles greater than one and one-half ($1\frac{1}{2}$) inches in their largest dimensions.

9. **Water.**—Water used for mortar and concrete shall be fresh and clean, free from earth, dirt, or sewerage, and shall be used in such quantity as the Engineer may direct.

10. **Platforms.**—Platforms shall be provided upon which all sand, gravel and broken stone shall be placed when brought upon the line of the work, and kept there until used.

11. **Mixing.**—Concrete may be mixed by hand labor or by machinery, but, in either manner, the thorough incorporation of the several materials required will be insisted upon. If machinery is employed for the purpose, its operation

must be subject to the direction of the Engineer Commissioner, as due consideration must be had as to the style, design and adaptability of the machine used to produce a mixture acceptable to him.

If the materials are mixed by hand labor, the operation must be performed on platforms of water-tight construction by competent labor, in accordance with the following instructions:

The dimensions of the platforms must be such as to provide an area sufficient to allow the entire mixing operations to be done upon them in a thorough and complete manner, in accordance with these specifications, and will depend upon the volume of the material used in the batch; in batches requiring a full barrel of cement, the dimensions of the platform will not be less than ten (10) by twelve (12) feet, or its equivalent area, of suitable form, and no larger batches than these shall be made by hand labor.

The required quantity of sand will be spread upon the board or platform, dry, and covered with the cement, in its proper proportion, when the material shall be thoroughly mixed and incorporated, by turning it with shovels not less than six (6) times. When sufficiently mixed, the mass will be so spread and shaped as to form a basin for the water which is to be added to make the mortar. The required quantity of water will now be poured into the basin thus formed and incorporated with the dry substance, by the use of hoes and shovels, so as to prevent any loss of material. The mortar will then be spread over the surface of the platform in an even and regular layer, preparatory to the reception of the stone and gravel, which, having been previously drenched, will immediately be deposited and evenly spread over the mortar.

When the entire quantity of the aggregate has been deposited and spread on the platform, as above, the mass shall be thoroughly mixed by turning it over with shovels, not less than four (4) times, until every particle of the metal has been completely enveloped in mortar; and until every particle is so enveloped, to the satisfaction of the Engineer Commissioner or his agent the mixing process must be continued. The order of turning must be so regulated that the last turn made will place the material in a single pile at or near the center of the board, preparatory to its removal to the place for it in the work.

In removing the concrete from the platform care must be taken to preserve the incorporation, which can best be done by shoveling it from the base at the edges of the pile, toward the center of it, and at the same time cutting down the apex of the pile with a hoe or shovel, in such manner as to avoid an accumulation of loose stones.

Stone and gravel used in the concrete must not be drenched in the vehicles used to deliver it upon the platform, unless proper arrangements are made to drain the receptacles, but shall be wetted before they are placed therein.

Concrete shall not be used after it has shown evidence of beginning to set, and no concrete that has once set shall be used as aggregate for a new batch. The work of mixing and spreading shall be done as expeditiously as possible.

Any material condemned as unfit for use, or not conforming to the specifications, must be immediately removed from the site of the work. The contractor must provide suitable facilities to determine the quantities and quality of the materials used in the concrete, so that they may be readily ascertained at all times.

12. **Laying.**—Grade stakes of suitable character must be set to determine and regulate the grade for the material as it is deposited in the work, and straight edges or other equally efficient devices used to insure a regular and

uniform surface between the stakes, and as the concrete is placed upon the sub-grade it must be regulated with shovels by skilled labor to conform to the grade immediately upon its emplacement, and then rammed or tamped sufficiently in place to form a solid and compact mass. The labor necessary to spread and compact the concrete must be other than that required to mix it. In compacting the material in place the operation of ramming or tamping must be continued until the top surface is regular and the water in the mass begins to appear on the surface. No mortar that has been prepared for the purpose of forming a new batch of concrete shall be taken to plaster any rough or improperly tamped places that may appear in the base, as ramming or tamping must be the only means employed to obtain a smooth and regular surface.

The removal and placing of the concrete to grade should be performed in such a manner as not to disturb the uniformity of the mixture.

Any lack of compaction or evidence of inferior setting in the base will be sufficient reason to require its removal and new concrete substituted for it.

If required, the earth in the sub-grade will be dampened before the concrete is laid, and the concrete base shall be sprinkled and wetted as often as required during dry or hot weather to prevent damage from too rapid evaporation, etc.

No cement concrete base shall be laid during very cold or freezing weather without permission of the Engineer Commissioner and then only under such special regulations and instructions as he may think necessary.

No hauling must be done over or upon the base, for any purpose until after it shall have sufficiently set to withstand fracture, and, if necessary, the base shall be planked before any hauling is done.

The specifications in use in Peoria, Illinois, are as follows:

CONCRETE FOUNDATION.

28. **Thickness.**—Upon the sub-grade prepared in accordance with the specifications for grading, will be laid a concrete foundation six (6) inches thick after being compacted.

29. **Proportions.**—The concrete shall be composed of one (1) part by bulk of American Natural Hydraulic Cement, one and one-half ($1\frac{1}{2}$) parts by bulk of clean, sharp sand, and four (4) parts by bulk of broken stone.

30. **Intention of Proportions.**—The proportions herein specified are intended to produce a concrete in which the mortar will fill all the voids, and the proportions will be so adjusted that when rammed in place free mortar will flush to the surface.

MIXING AND SPREADING CONCRETE.

31. **Mixing Sand and Cement.**—The sand and cement shall be thoroughly mixed dry in a tight mortar box and then made into a mortar of the proper consistency and thoroughly worked over with hoes. Broken stone thoroughly cleaned of dirt, drenched with water, but containing no loose water in the heap, shall then be added to the mortar in the proper proportion. The concrete will then be turned and mixed until mortar adheres to each fragment.

32. **Consistency of Concrete.**—The concrete thus mixed shall have such a consistency that when rammed the mass will not shake like jelly; but will when struck, compact within the area of the face of the rammer without displacing the material laterally.

33. **Immediate Use of.**—The concrete thus prepared shall be immediately placed in the work. It shall be spread and thoroughly compacted by ramming until free mortar appears on the surface.

34. **Mixing and Laying.**—The whole operation of mixing and laying each batch of concrete shall be performed in an expeditious and workmanlike manner, and be entirely completed before the cement has begun to set.

35. **No Re-tempering.**—No re-tempering of concrete will be permitted, and concrete in which mortar has begun to set will be rejected.

36. **Conform to Grade.**—The upper surface of the concrete shall be made to conform exactly to the form of the pavement to be laid, and shall be made perfectly smooth by thoroughly brooming with wire brooms.

37. **Protection.**—As soon as laid, and before the top becomes dry, the entire surface of the concrete foundation shall be covered with one (1) inch in depth of clean sand to protect it from the sun and wind. The sand so spread shall be kept moist until the pavement is laid.

38. **Time for Setting.**—No driving over the concrete foundation will be permitted, and it shall be allowed to set for four days before any further work shall progress on the same, and any damage done by passing over it shall be repaired by the Contractor without extra pay.

39. **Minimum Temperature When Laid.**—No concrete shall be laid when the temperature at any time during the day or night falls below thirty-five (35) degrees Fahrenheit.

SPECIFICATIONS FOR CONCRETE CURB.

The specifications in use in Peoria, Ills., are as follows:

SPECIFICATIONS FOR CONCRETE CURB.

1. The curbing herein specified shall be constructed on.....
.....Street, from.....Street
to.....Street.
2. The concrete curb shall be.....inches in
thickness and.....inches wide, with the upper face corner
rounded to a radius of one and one-half ($1\frac{1}{2}$) inches.
3. The curb shall be constructed on the ground in alternate sections,
and the top edge shall conform to the line and grade given by the Engineer.
4. After the necessary excavation has been made along the line of the
proposed curbing, there shall be laid a foundation of cinders twelve (12)
inches wide and six (6) inches in thickness after being compacted; this bed of
cinders to be flooded with water and thoroughly rammed to a true and even
surface with a hand rammer weighing not less than forty (40) pounds.
5. Upon this bed of cinders shall be set the curb, which shall be con-
structed so as to form a solid mass, divided every seven (7) feet of its length
into separate stones, and the concrete portion of which shall be composed
of one (1) part best imported Portland cement, three (3) parts clean, sharp,
well-screened sand, and five (5) parts hard limestone or granite crushed to
such size that the fragments shall not be larger than one (1) inch in the
greatest dimension.
6. A facing one (1) inch in thickness shall be constructed on the top
and street face of the curb for a distance of.....inches from the
top. This facing shall be composed of one (1) part best imported Portland
cement and one and one-half ($1\frac{1}{2}$) parts fine granite screenings, and shall
be carried up simultaneously with the concrete, same being plastered upon
the front board of the frame immediately previous to placing the concrete.
After the frame has been removed the facing shall be neatly troweled to a
true, smooth surface.
7. The crushed granite shall be entirely free from dust or dirt, and
broken to such size that no piece shall exceed one-fourth ($\frac{1}{4}$) of an inch in
its greatest dimension.
8. The curb shall be protected from the sun and wind by a covering
of canvas or plank, or sprinkling it with water for at least twenty-four hours
after completion.
9. The finished curb shall be of a uniform color, and sections which
do not correspond in color with the remaining portion of the curb must
be replaced. Any spalling or splitting off whatever of the finished surface of
the curb, either at the joints or in the body of the stone, will be sufficient
cause for rejection, and any rejected stone must be removed and replaced with
a new one immediately. No patching, of any character, will be permitted.
10. The Contractor will be required to enter into a bond to guarantee
the curb for a period of five (5) years after the completion and acceptance
of the work against any settlement, cracks, discolorations, or any other
defects due to bad materials or faulty workmanship which shall appear therein
within the above period.
11. Circular curb stones will be constructed in the same manner as
straight curb at the entrance to all alleys and driveways, and at the corners
of all intersecting streets.
12. The sand and cement shall be thoroughly mixed dry in a tight mortar
box and then made into a mortar of proper consistency and thoroughly worked

over with hoes. Broken stone or gravel thoroughly cleaned of dirt, drenched with water, but containing no loose water in the heap, shall then be added to the mortar in the proper proportion. The concrete will then be turned and mixed until mortar adheres to each fragment.

13. The concrete shall have such a consistency that when rammed the mass will not shake like jelly, but will, when struck, compact within the area of the face of the rammer without displacing the material laterally.

14. The concrete thus prepared shall be immediately placed in the work. It shall be spread and thoroughly compacted by ramming until free mortar appears on the surface.

15. The whole operation of mixing and laying each batch of concrete shall be performed in an expeditious and workmanlike manner, and be thoroughly completed before the cement has begun to set.

16. No retempering of concrete will be permitted, and concrete in which the mortar has begun to set will be rejected.

CHAPTER VI.

MACHINERY AND TOOLS,

It is not the object here to present anything upon the machinery used in the manufacture of cement, but upon the implements used in the making of concrete, cement mortar, and mortar and concrete work.

ROCK CRUSHERS.

It is frequently cheaper to buy and install a rock crusher with the necessary power to operate it than it is to buy the stone already crushed and pay for shipping it from a distance and hauling it upon the work.

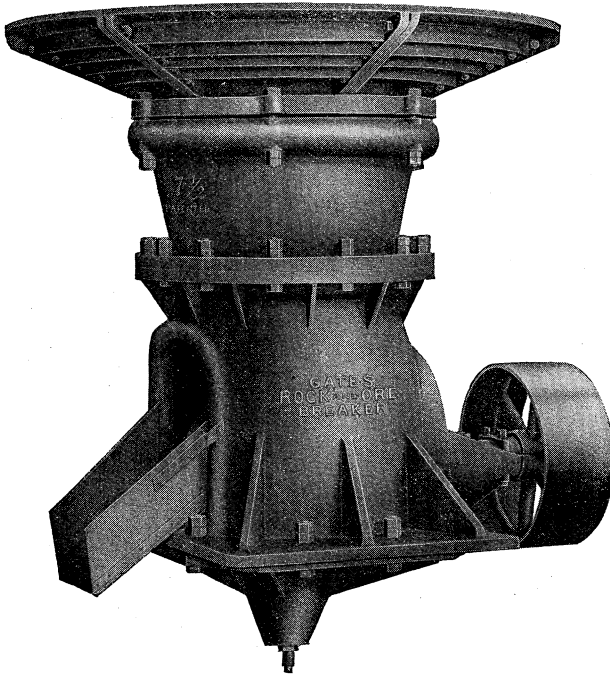


Fig. 124.—Gates' Gyratory Crusher, No. 7½.

There are a good many kinds of rock crushers in the market; a few illustrating the different types will be presented here. Figure 124 shows

a Gates crusher. It is a gyratory crusher, having a heavy rotating head or cone within the shell, which gyrates eccentrically, crushing the stone between the gyrating head and the stationary outer shell.

Figure 125 shows a section through the machine more clearly illustrating the principle. It is claimed for this form of stone crusher that it

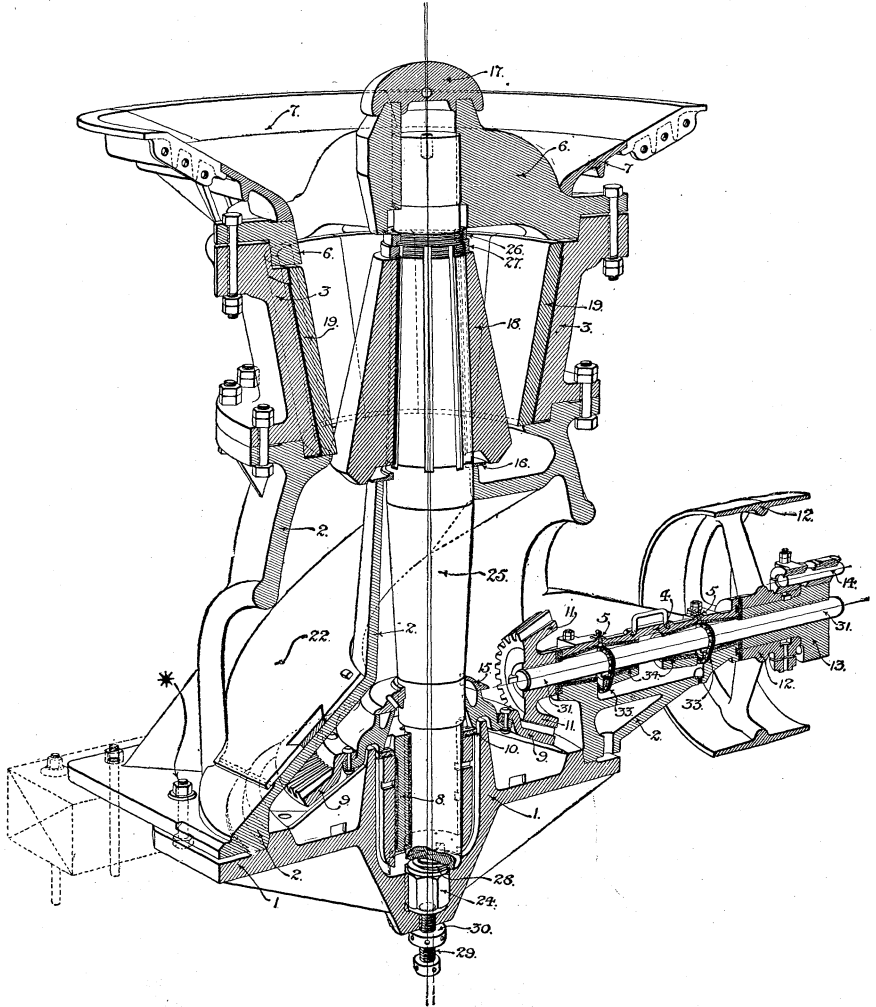


Fig. 125.—Section of Gates' Crusher.

The names of the several parts designated by numbers in the above illustration may be found in the following table:

1 Bottom Plate	11 Bevel Pinion	24 Octagon Step
2 Bottom Shell	12 Band Wheel	25 Main Shaft
3 Top Shell	13 Break Hub	26 Upper Ring Nut
4 Bearing Cap	14 Break Pin	27 Lower Ring Nut
5 Oil Cellar Cap	15 Oil Bonnet	28 Steel Step
6 Spider	16 Dust Ring	29 Lighter Screw
7 Hopper	17 Dust Cap	30 Lighter Screw, Jam Nut
8 Eccentric	18 Head	31 Counter Shaft
9 Bevel Wheel	19 Concaves	33 Oiling Chain
10 Wearing Ring	22 Chilled Wearing Plates	

requires 30 per cent. less power under similar conditions to do the same amount of work which can be done by the other form of machine—the jaw crusher. It is also claimed that, because of the concave stationary surface and the impact of the revolving cone at the unsupported center of the masses of stone, a more perfect cubiform product is obtained.

Naturally it requires more power to break stone to one-half inch size than it does to break it to two and one-half inch size. This must be taken into account in ordering machines. The manufacturers of this machine claim that "The Gates' breaker will not require over one horse power per ton of rock broken per hour," for the hardest stone broken so as to pass a $2\frac{1}{2}$ inch ring.

Figure 126 shows a section of the Austin portable crusher, which is a very simple machine of a similar type.

Figures 127 and 128 show view and section of the Farrel crusher, a very substantial compact machine of the jaw crushing type.

SCREENS.

Figure 129 illustrates revolving screens. The perforated screen sheets are easily removed and replaced when worn out, or they can be changed quickly when other sizes of stone are required.

Cheaper gravity screens can be used, but they are not quite so efficient in screening. They are of perforated sheet metal, as the revolving screens, but are in flat sheets and attached in the bottom of inclined chutes down which the crushed stone is allowed to slide dropping through the holes in the various sections as the size of aperture admits.

CONCRETE MIXERS.

There are numerous forms of concrete mixers, and many makers of the same form. At first engineers were averse to accepting machine mixed concrete, fearing inferior mixing, improper proportions of water and various other troubles. Now a large majority of engineers prefer machine mixed concrete, electing, however, to choose the form of mixer which shall be used.

The Drum Mixer.—The Ransome patents cover a drum mixer, a cylindrical machine having openings at either end and resting upon friction rollers. It is driven by cog wheels working in a cogged rim to the drum and the whole driven by steam, air, or electricity.

Inside this drum are kneading wings for mixing, and hinged shelves by which the concrete is lifted and thrown into a chute. These shelves are set for mixing or discharging by the movement of a single lever without stopping the machine. Figures 130 and 131 show the receiving and discharging ends of the machine respectively.

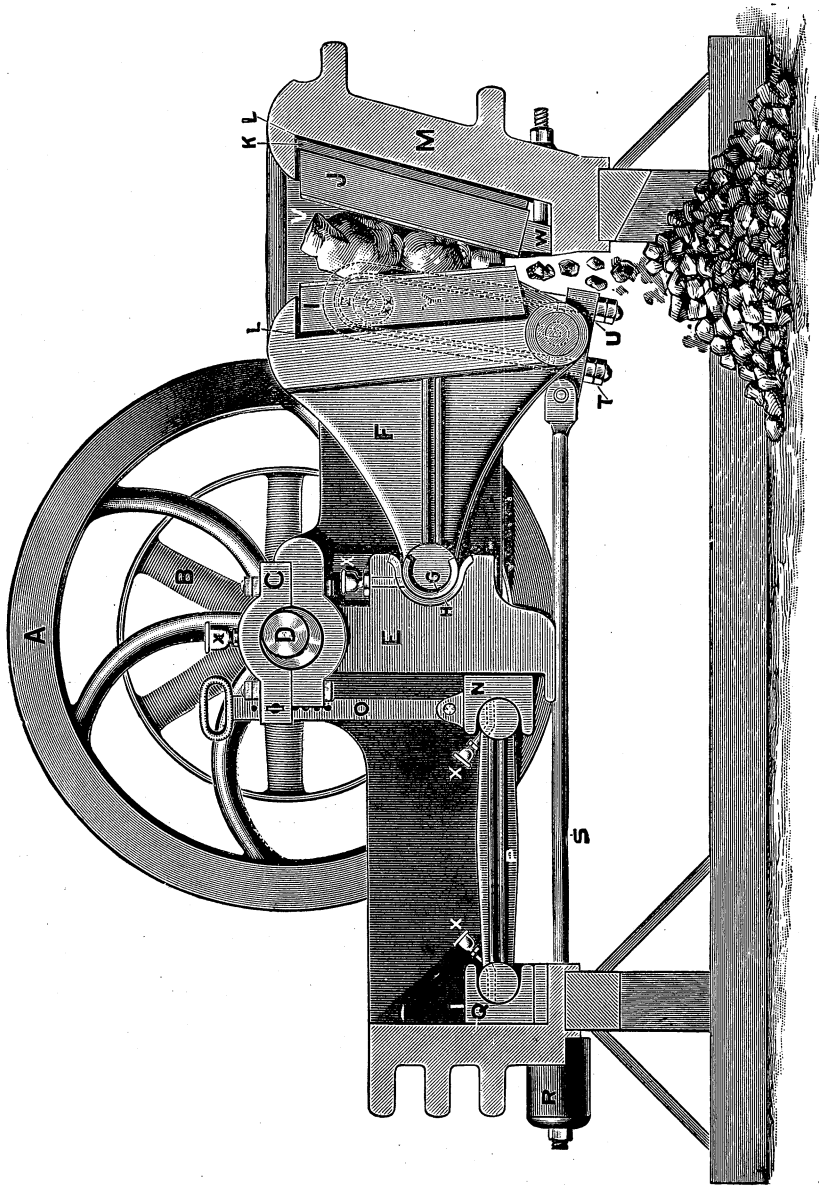


Fig. 126.—Austin Jaw Crusher.

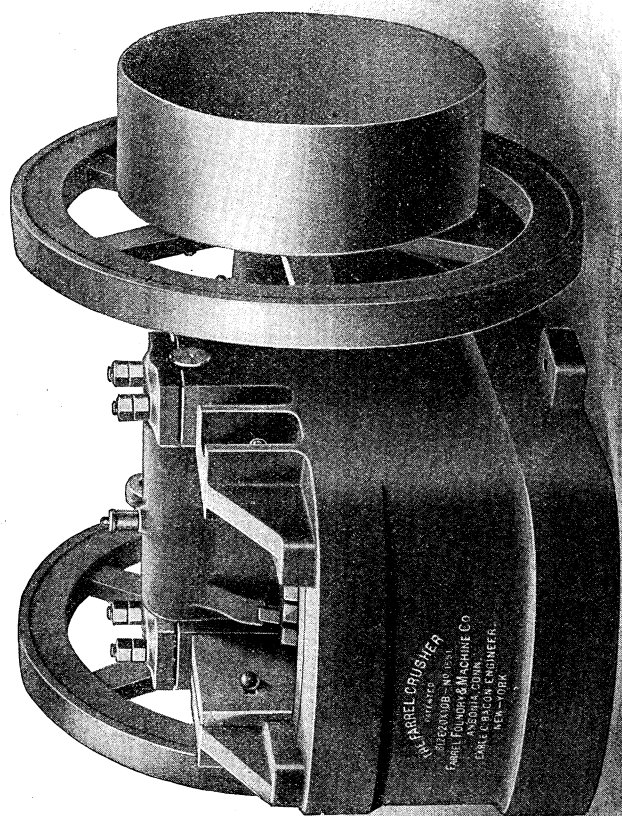
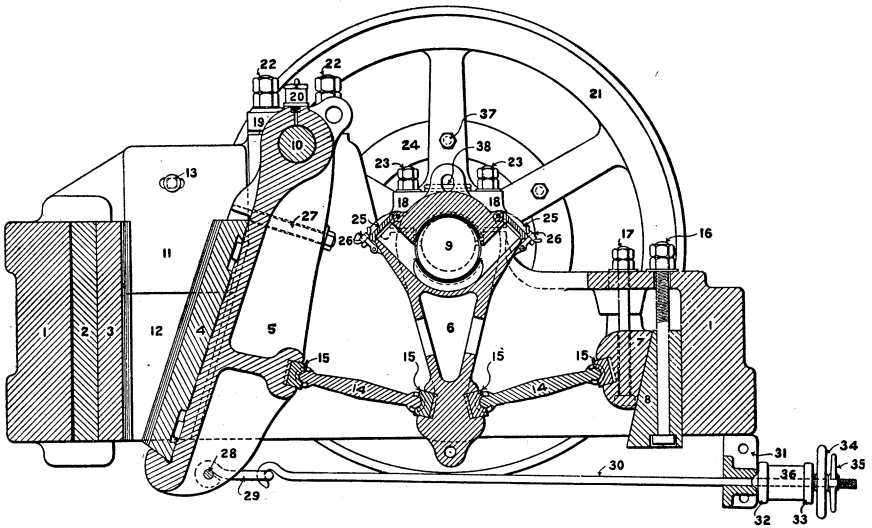


Fig. 127.—Farrel Jaw Crusher.



SECTIONAL VIEW OF FARREL "STYLE B" CRUSHER

Name and Number of Parts.

1 Main Frame	9 Eccentric Shaft	17 Bolt for Toggle Block	25 Grease Box Cover	33 Washer
2 Round Back	10 Swing Jaw "	18 Cover " Main Bearing	26 Bolt and Thumb Screw	34 Hand Wheel
3 Fixed Jaw Plate	11 Upper Half Cheek Plate	19 " " Swing Jaw Shaft	27 Bolt for Swing Jaw Plate	35 Thumb Nut
4 Swing " "	12 Lower " " "	20 Grease Cup	28 Shackle Pin	36 Rubber Spring
5 Swing Jaw	13 Bolt for " "	21 Balance Wheel	29 Spring Rod Shackle	37 Bolt for Pulley
6 Pitman	14 Toggle	22 Bolt for Swing Jaw shaft cover	30 Spring Rod	38 Grease box cover
7 Toggle Block	15 Toggle Bearing	23 " " Main Bearing	31 Spring Bar	on Main Bearing
8 Wedge	16 Bolt for Wedge	24 Pulley	32 Washer	

Fig. 128.—Sectional View of the Farrel Crusher.

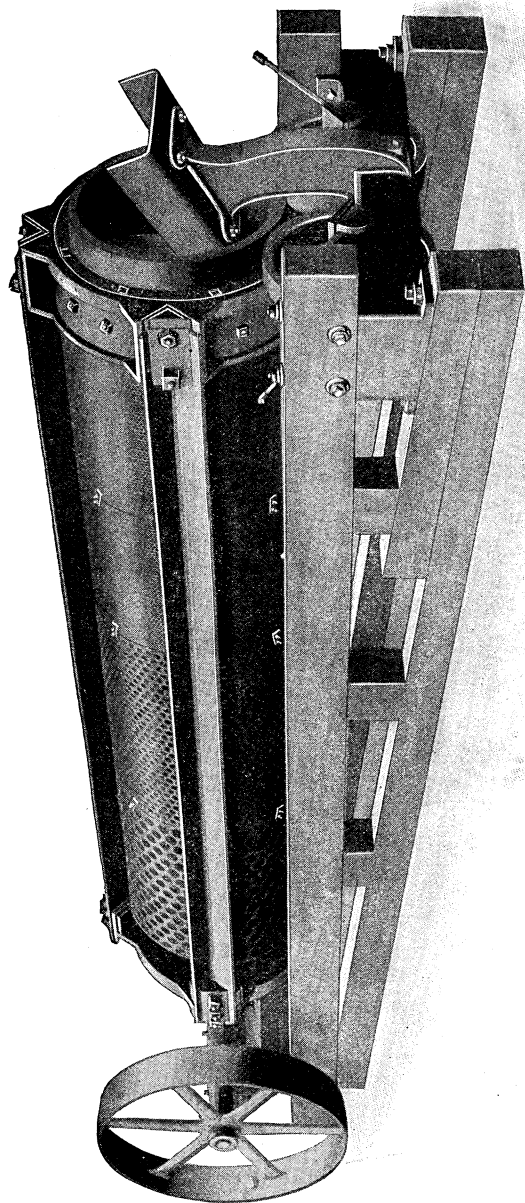


Fig. 129.—Gates' Revolving Screen.

"Passing through the drum and supported upon the truck is a folding chute which receives the concrete from the drum and delivers it to the wheelbarrow or other receptacle used for conveying the concrete away."

Inside of one minute the material has all been turned over thirty or forty times and is well mixed. This mixer will mix 200 to 400

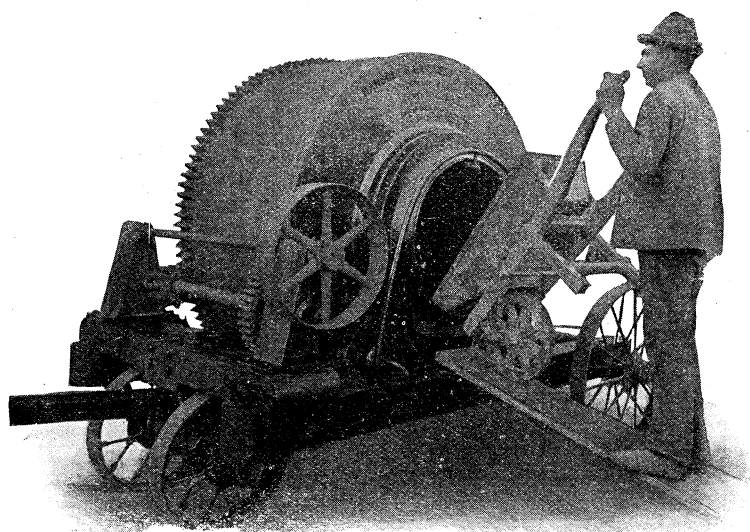


Fig. 130.—Ransome Drum Mixer, Charging.

charges a day." Ransome claims to be able to mix concrete at a cost of 2 cents per cubic yard.

Smith Mixer.—The Smith concrete mixer consists of a revolving drum or double cone with horizontal axis, constructed with deflecting wings on the inside. The end of each cone is open, one serving as the loading end, the other for the discharge end. The concrete is visible during the entire period of mixing and can be discharged without stopping the machine. The thoroughness of the mixing depends upon the time spent or the number of revolutions given. Whenever the writer has seen the machine in operation it has been turning out an excellent product. Figure 132 shows the discharge end view of the Smith machine.

	No. 0	No. 1	No. 2	No. 2½	No. 4	No. 5
Standard charge, cubic feet.....	5	9	13½	16	21	28
Extreme capacity, cubic feet.....	6	12	17	21	23	35
Cubic yards mixed per hour, up to.....	5	10	16	20	22	35
Horse power required.....	3	6	8	10	14	18
Weight on skids with pulley only, in pounds	1,600	2,500	3,800	4,500	5,570	7,300

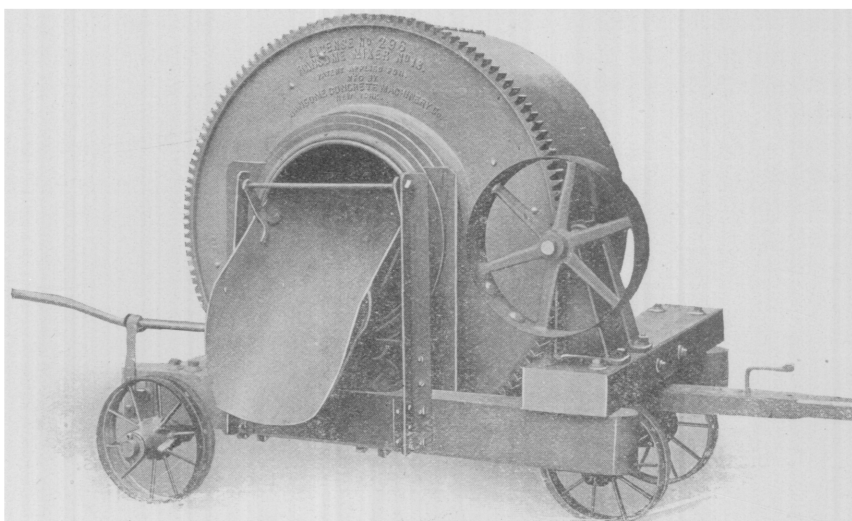


Fig. 131.—Ransome Drum Mixer, in Position of Discharging.

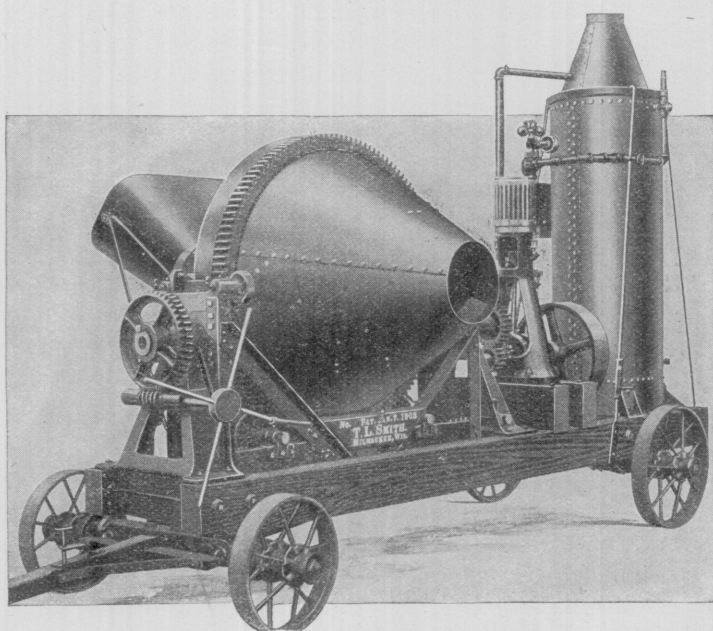


Fig. 132.—The Smith Mixer.

Campbell Mixer.—The Campbell machine consists of a horizontal circular pan revolving about a vertical axis and having a set of stationary plows fixed to a frame which can be raised or lowered into the pan. The pan carries the material against the plows and they throw the material back and forth in the pan as it revolves until the concrete is thoroughly mixed. A trap door in the bottom of the pan is then opened and the plows raised, while a scraping bar is lowered and the batch of concrete is scraped and dropped through the trap door into the transporting receptacle below. There are two sets of plows, one right hand and the other left hand.

“Time actually consumed in charging machine for one yard of concrete, completing the mixture and dumping the machine ready for the next batch, three minutes and ten seconds.” Illustrations of the machine are given in figures 133 and 134. Specifications of size, weight and capacity are also appended.

Cubical Mixers.—There is a variety of cubical mixers, probably developed because the United States army officers at one time threw the weight of their commendations toward that form of mixer. This general form is supported so as to revolve upon a diagonal axis and thus throw the concrete mixture from one to the other of six different faces, each rapidly assuming a different angle to the horizontal and vertical planes as the cube revolves. One form of the cubical mixer is shown in figure 135. This is so arranged that it can be loaded at one end and discharged at the other, both operations taking place without stopping the machine's rotation.

Gravity Mixer.—Figures 136 and 137 show a simple gravity mixer which answers very well for some purposes. It consists of a funnel shaped receiving end attached to a box shaped chute having staggered rows of pins at frequent intervals along its length. It is also fitted with deflecting plates to throw the material from side to side as it descends through this chute, which is suspended at an angle of about 20 to 25 degrees from the vertical. The box is made in sections easily joined together so that various lengths, from four to ten feet, may be used for different classes of work and surrounding conditions. There is some doubt as to the thoroughness of the mixing obtained, also as to the even tempering of the mixture with water. There is much rough concrete foundation work, however, where this simple form of mixer might be satisfactory. Limited space allows the description of but one of the many other forms of mixers.

Dromedary Mixer.—The Dromedary mixer is a unique development of the two wheeled cart. The inventor evidently designed this to answer two purposes, first to utilize horse power to do his mixing, and second, to utilize for mixing, the power and time necessary to haul the material to

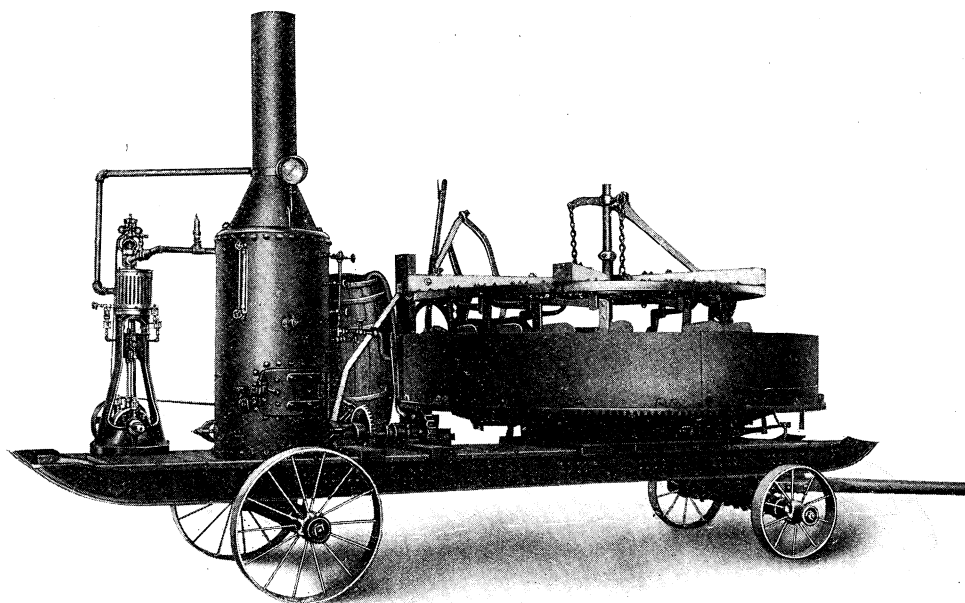


Fig. 133.—The Campbell Mixer, Steam Driven.

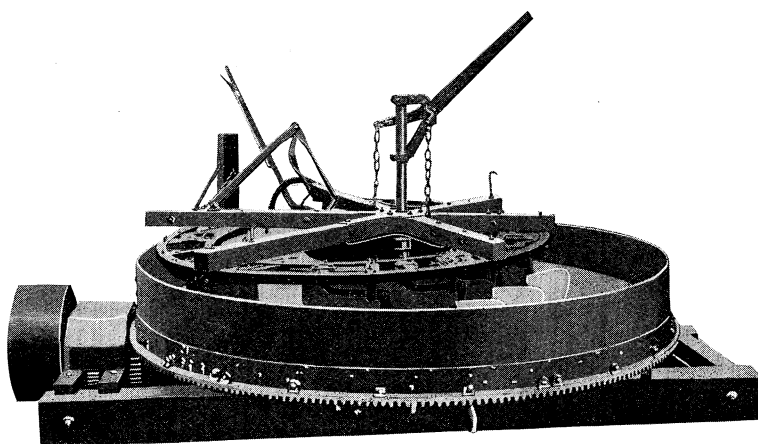


Fig. 134.—The Campbell Mixer, Horse-power Driven.

SIZE.	No. 1.	No. 2.	No. 3.
Weight on steel skids.....	3,000 pounds	4,000 pounds	5,500 pounds
Weight on wheels.....	4,000 pounds	6,000 pounds	.....
Weight of engine and boiler.....	1,400 pounds	1,700 pounds	2,700 pounds
Capacity per batch.....	$\frac{1}{3}$ yard	$\frac{1}{2}$ yard	1 yard
Batches per hour.....	30	30	25
Power required.....	3 horse-power	4 horse-power	6 horse-power
Diameter of mixing pan.....	6 feet 6 inches	9 feet	11 feet.

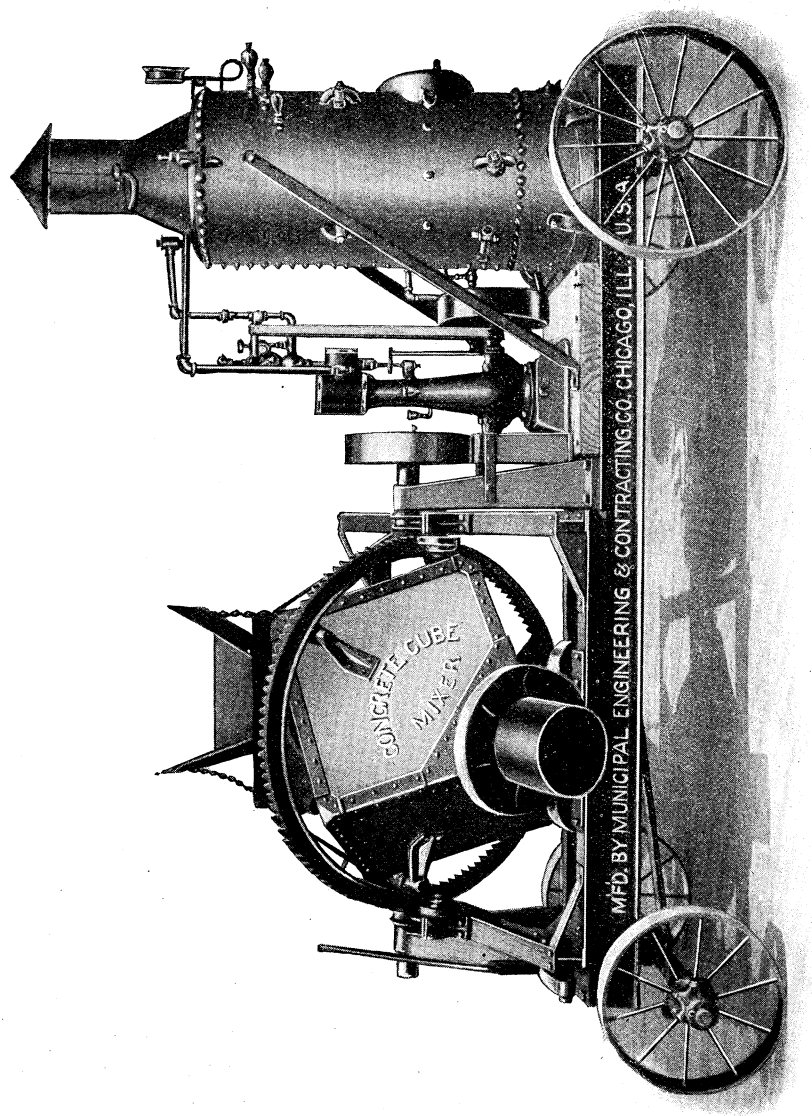


Fig. 135.—Cubical Mixer, Discharging Position.

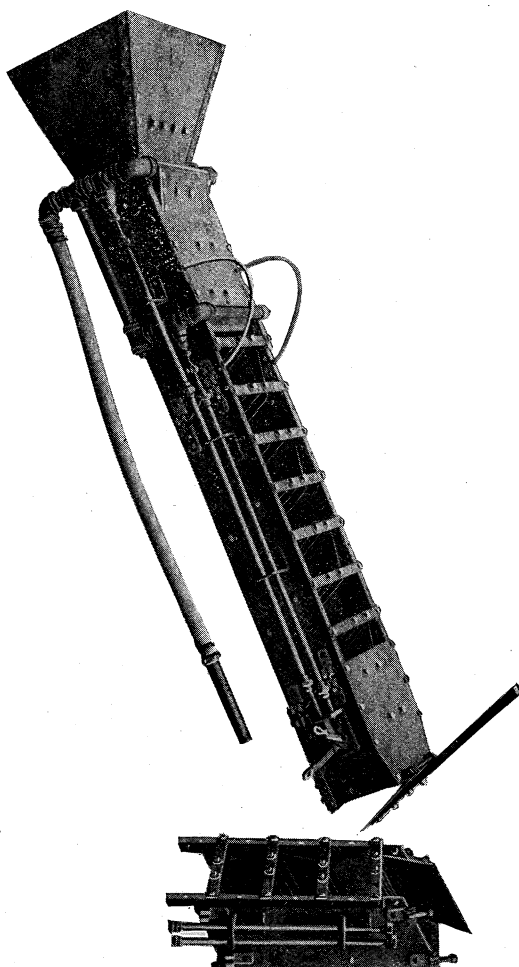
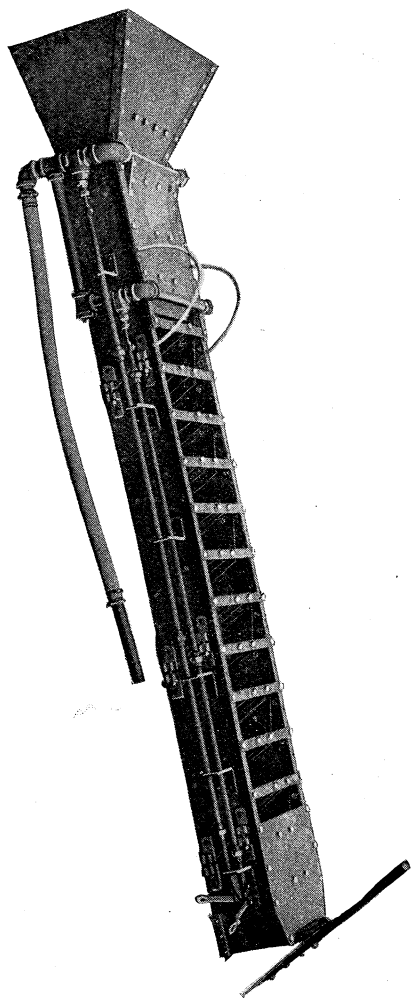
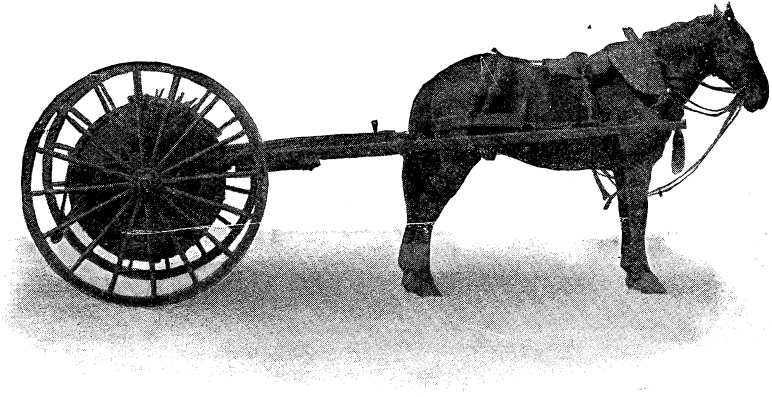


Fig. 136.—Gravity Mixer, Full Length. Fig. 137.—Gravity Mixer, With Short Section Out.

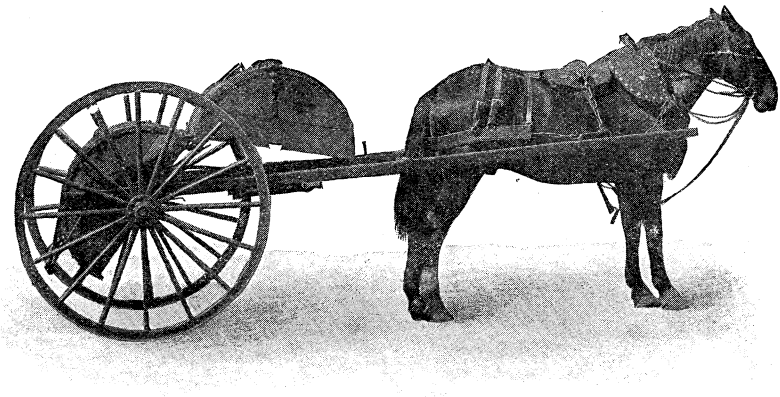
the point of construction. The machine consists of the two halves of a cylindrical drum, hinged together at one edge and closing by a spring and catch at the other. It is mounted upon the axle of a two wheeled vehicle. The drum is also so constructed that it can be made to revolve as the



LOADED

Fig. 138.—The Dromedary Mixer, Loaded.

wheels revolve, or it can be thrown out of gear and allowed to swing free. In one side is a door, through which the drum is loaded. When loaded, (see figure 138) it is thrown in gear and the horse hauls the dromedary drum to the point of discharge. The concrete is mixed by being carried



DUMPING

Fig. 139.—The Dromedary Mixer, Dumping.

up the side of the revolving drum and sliding and falling in thin sheets over the mass of material within. In unloading a bar is unlatched which causes

one-half of the drum to slide forward upon the frame work of the sulky and the batch is delivered upon the ground, thus leaving the drum in the position shown in figure 139, which gave it the name "Dromedary Mixer." It is especially useful where conduit or street work is being done and the material must be stored at intervals along the line of work, and must be conveyed some little distance to the point of construction. These machines are made in size for about one-half yard batches and cost \$250.00 apiece, F. O. B., Washington, D. C.

MOLDS.

The first forms or molds used were simply constructed of planed lumber well braced and were for monolithic structures. The forms used by the Ransome Company in their concrete construction consist of short lumber frames reinforced with joists and bound together through the walls with rods and wires. These forms are raised for every three or four feet in elevation of the wall.

Thos. C. Farrell, of Washington, N. J., has designed a set of adjustable forms for monolithic concrete construction that is quite simple in adjustment. Metal shoes and "box caps" of cast iron shaped in the form of an extended H make the holders for two inch plank. Figure 140 illustrates their method of use under almost every condition to be met. The shoes and cross bolts leave holes and indentations in the walls which must be plastered up and smoothed over with cement mortar in order to make the wall have a smooth uniform appearance. By the aid of these forms but a comparatively small amount of lumber is necessary to carry on relatively large building operations. The operation is to set one course of ten inch planks around the entire structure as shown in the illustration, fill with concrete and tamp. Set up another course and fill with concrete, and so continue until four ten inch courses are filled. Then remove the bottom course and place it on top and proceed in this manner to the finish. By this method, the course to be tamped never exceeds ten inches in depth. The builder can reduce the thickness of the layers by making three layers of concrete to two tiers of plank if he so desires. These forms are easily set up, taken down and moved from one structure to another.

The Clark Patent Circular Mold is another form for monolithic construction. It consists of an inner and outer metal shield or form, braced and reinforced, leaving an annular space for the monolithic wall. It is especially designed to fill the demand for concrete silos, tanks, grain bins, manholes, etc.

BLOCK MACHINES.

The block machines are all very similar in general principles, but differ in minor mechanical applications.

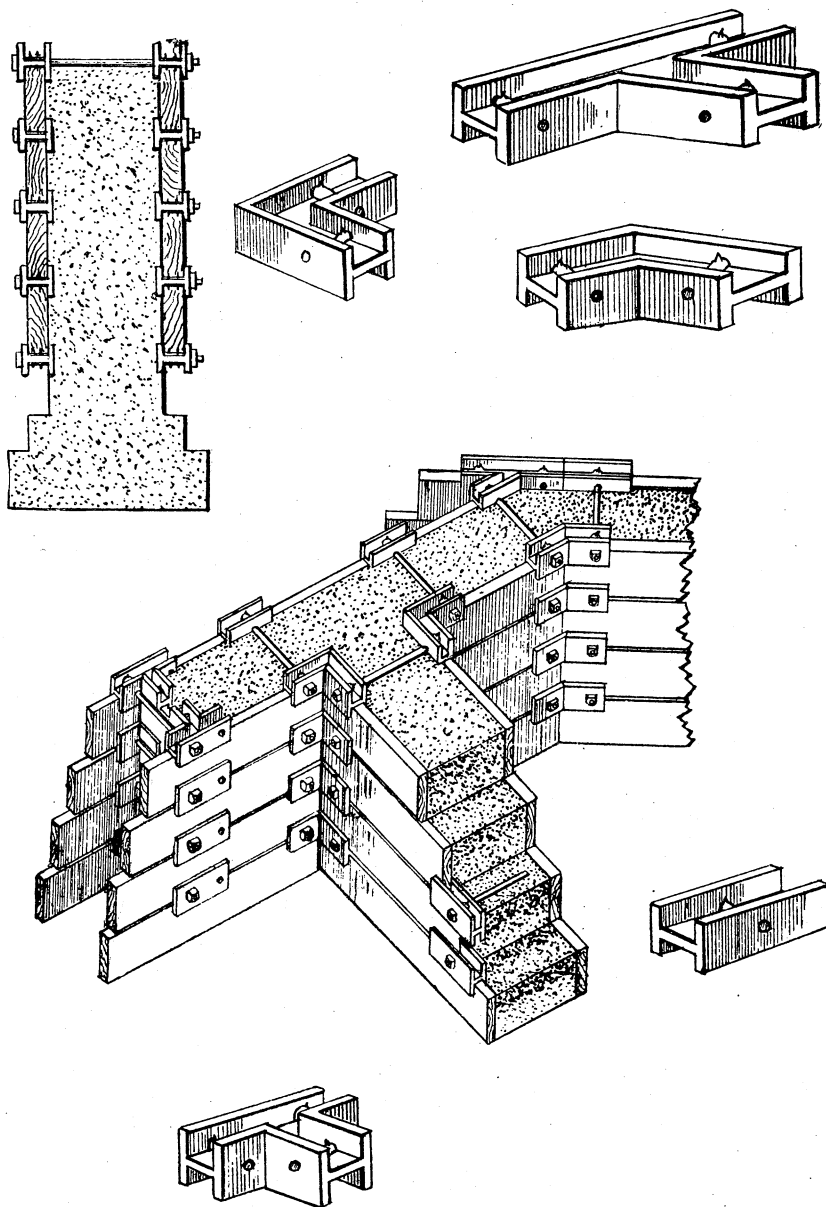


Fig. 140.—Farrell System of Molds for Concrete Wall Construction.

The Winget Machine, manufactured in Columbus, Ohio, is illustrated in figures 141 and 142. One ideal which all block machine makers strive to attain, is the elasticity in size and shape of their blocks. Most block machines attain this ideal to a greater or less degree. Another requirement is to keep strength and reduce material, which is accomplished by making the block hollow—this also makes walls which keep more equable temperatures within the structure, and which aid in preventing moisture reaching the interior surface of the walls.

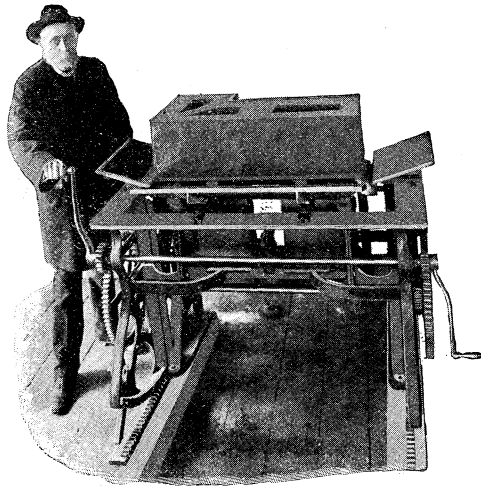


Fig. 141.—The Winget Concrete Block Machine, Showing Block Ready to be Removed.

The Winget machine is so adjusted that the sides of a block can be faced with a richer mortar half or three-quarters of an inch thick. This gives a neater, smoother face to the stone and makes it less pervious to water. If desired, this outer shell can be colored, giving a very fair imitation of natural stone without being expensive in coloring matter. It is said that four men using this machine can produce 150 blocks per ten hours. The usual size is 9 inches by 10 inches by 32 inches. The Winget machine makes blocks having very sharp, neat, well defined corners, which is an essential to neat construction. The Winget Concrete Machine Company claim that blocks can be made with their machine and laid for about thirty cents apiece. Figure 143 shows the various shapes and patterns of blocks made in a Winget machine.

The Normandin Machine.—The Normandin machine also seems to be a very good machine. Figure 144 illustrates this machine. Similar to nearly all of the other block machines it has adjustable or exchangeable sides so that face designs can be substituted for plain faces.

The Palmer Machine.—The Palmer machine is one of the first designed of this class of machines. A great many neat houses have been

put up with the Palmer block. This machine, samples of blocks made upon it, and illustrations showing the use of its products are shown in figures 23, 24, 25, and 26.

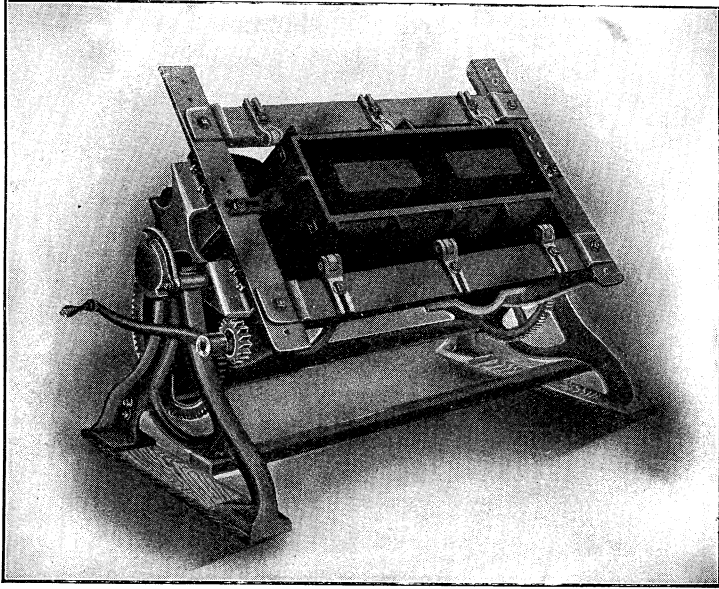


Fig. 142.—Winget Concrete Block Machine Empty.

The Dykema Machine.—The Dykema mold is illustrated in figures 145 and 146, the method of filling in figure 147, and the results accomplished, in figures 148, 149 and 150. The molds are made of sheet steel pressed into the desired shapes. There are seven lugs at each end of the side pieces allowing the adjustment of the end pieces in such a way as to permit the length of stone to vary from 19 to 25 inches. By the use of a special double core and dividing plate a still greater flexibility of length is given varying from a least length of $4\frac{1}{2}$ inches up to the 25 inches.

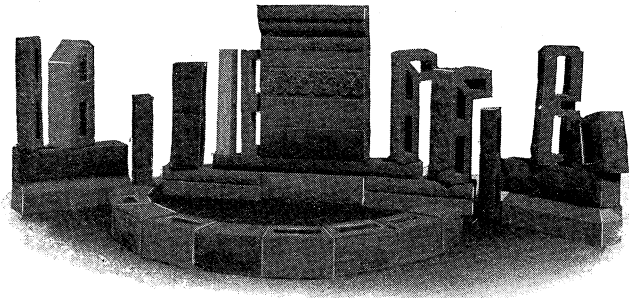


Fig. 143.—Collection of Concrete Blocks, Made on the Winget Machine.

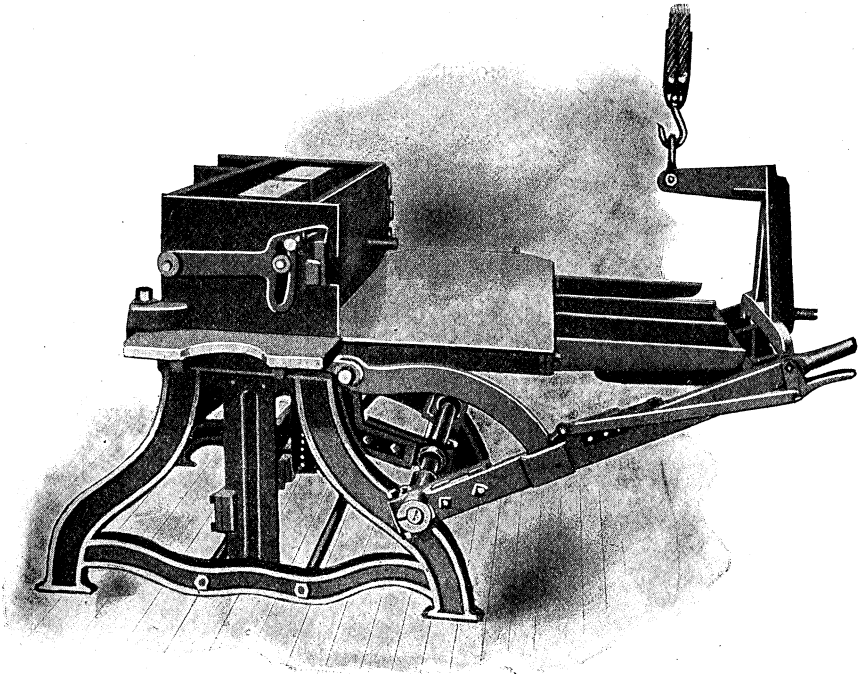


Fig. 144.—The Normandin Concrete Block Machine.

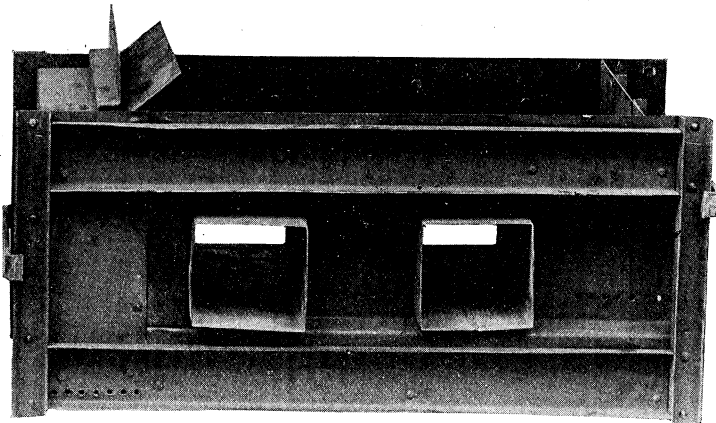


Fig. 145.—The Dykema Block Machine.

The stone manufactured by the Dykema process is made of very wet concrete, so wet that it will flow into place around the cores. Mr. Dykema claims that by this means he gets a denser concrete and at a considerable saving in labor. For work which compares with common brick work, the material is "struck" across the top of the mold after filling and troweled, but for finer natural stone effects, a surface coat of sand and cement is

added to the top of the block and fine sand or siftings of some natural stone are sifted over the surface producing the natural stone appearance. The form of the block, as shown in figure 149, affords an excellent means of handling the stone upon the wall. The company claim to do the work for the following prices, quoting from Dykema's "Stone Making."

Cost of Stone.—"Figures here given are from actual experience and based on the labor of men mixing by hand, and on the cost of labor and material in Grand Rapids.

The 12 inch stone lays 1.35 square feet in the wall, including a $\frac{1}{2}$ inch mortar joint. This is equal to 30 bricks. One man can make 40 to 50 of these stone in a day, doing all the labor of setting up the mold, mixing the material and finishing the stone. With "*correct concrete*" 40 of these stones can be made from one barrel of Portland cement. Based on a day's work for one man a 12 inch stone figures as follows:

Labor	\$0.04
Cement, 40 stone to the barrel, at \$1.50 per bbl. .	0.03 $\frac{1}{4}$
Gravel and sand	0.03
Total	\$0.10 $\frac{3}{4}$

This is equal to \$3.58 per 1,000 for brick. The 10 inch stone lays the same surface in the wall, 10 inches thick. The cost is as follows:

Labor	\$0.03 $\frac{1}{2}$
Cement	.03
Gravel and sand	.02 $\frac{1}{2}$
Total	\$0.09

These stones are sufficiently strong to replace any work which would otherwise be built of 12 inch brick walls."

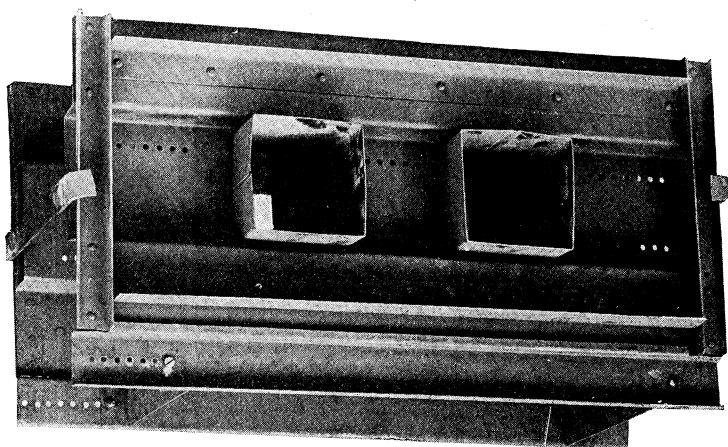


Fig. 146.—The Dykema Block Mold.

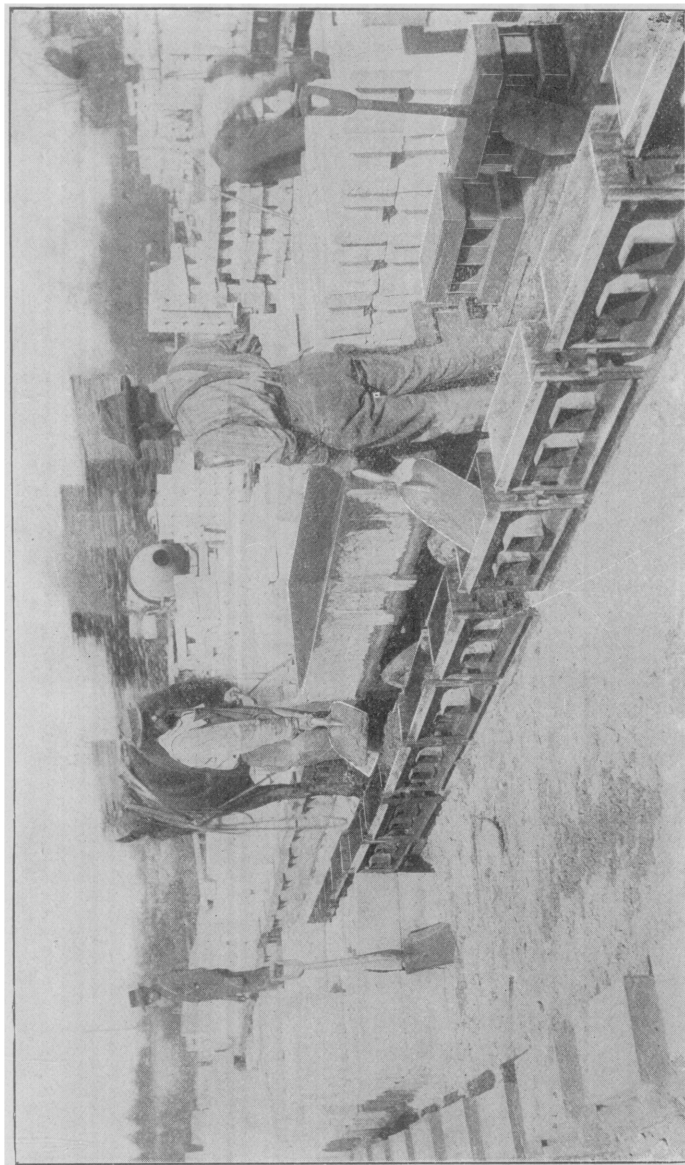


Fig. 147.—Filling the Dykema Molds.

For conditions at Columbus, these figures could not be substantiated. Assuming it possible to make 40 blocks a day, labor at \$2.00 per day.

Labor, per block.....	\$0.05
Cement, 40 stone to the barrel, at \$2.00.....	.05
1½ yds. gravel and sand at \$1.60 per cu. yd.....	.06
Cost per block	\$0.16

To this must be added the interest and depreciation on the cost of the plant.

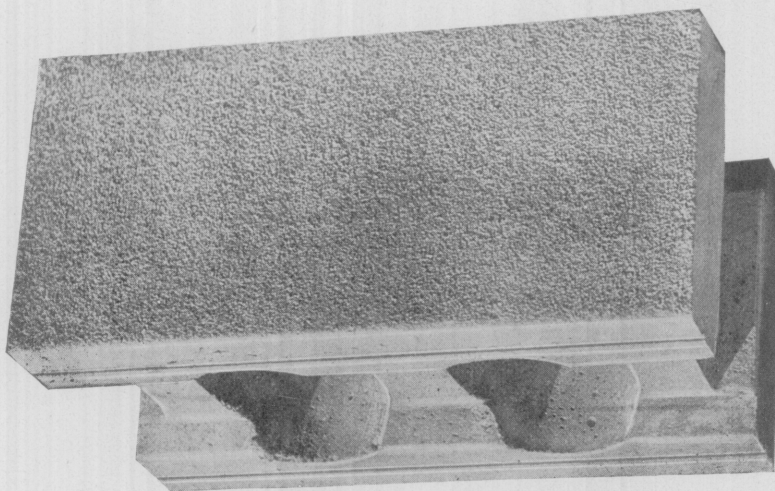


Fig. 148.—Dykema Block, Pebble Finished.

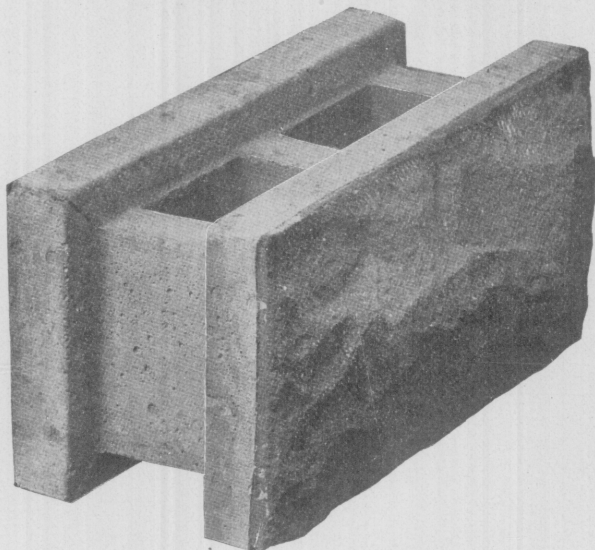


Fig. 149.—Dykema Block, Granite Finished.

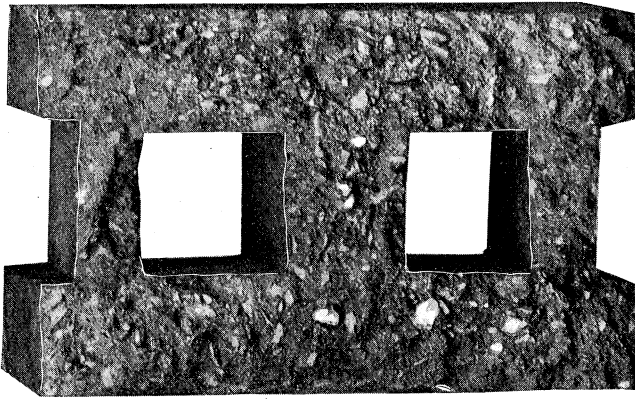


Fig. 150.—Interior Structure of Dykema Block.

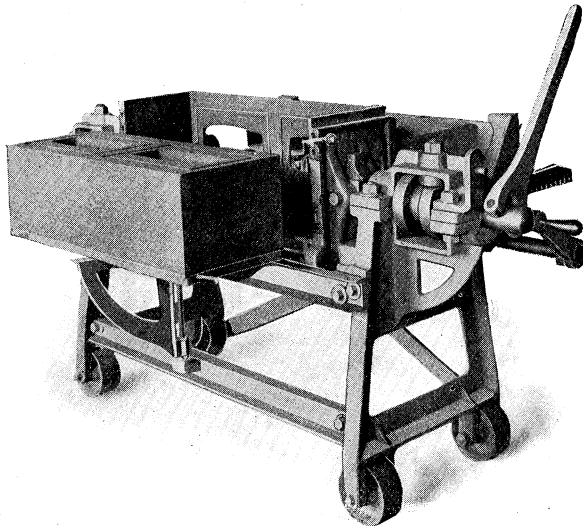


Fig. 150a—The Hayden Machine.

The Hayden Machine.—The Hayden machine, manufactured in Columbus, Ohio, is an automatic block machine in which the blocks are made face down, with the face in a horizontal position. This enables the operator to easily give a veneer facing of rich mortar to the block or to make the face of colored mortar in imitation of natural building stones. The machine is very compact and turns out blocks with corners and edges sharp and true. It automatically releases the block from the mold, delivering it upon a base plate to a support in front of the machine, ready to be carried away. The machine will make blocks 8 to 16 inches thick and 8 to 32 inches long.

Figure 150a illustrates the original Hayden machine. Experience has shown them that this machine is set too high and is not rigid enough. In the later machines now coming from their shops, they are reducing the height of the frame and making it much heavier.

TOOLS FOR CEMENT WORK.

Among the tools for the use of cement as in sidewalk, curb, street work, etc., come first the tools for hand mixing and handling. As these tools are common to many forms of work even to gardening, no illustrations or descriptions will be given. Among such tools are the shovel, hoe, rake and wheelbarrow.

Round and square iron tampers are the best for concrete work. Probably the square tamper is more serviceable for all kinds of work, because it will fit into corners. For some classes of work, such as facings in narrow places, the narrow or edge tamper is required. Figure 151 shows the foot of the square tamper. Prices are quoted by one maker ranging from \$3.20 for the 6 by 6 inch to \$4.80 for the 12 by 12 inch, all bases being $\frac{1}{2}$ inch thick. These prices are subject to discount. Another maker quotes same tool from \$1.00 upward.

The following figures illustrate the various implements used in concrete work, their names being sufficiently explanatory of the uses to which they are placed.

For the purpose of preventing slipperiness and to give a good foothold for horses, line rollers and indentation rollers are used upon the freshly troweled surfaces of walks, driveways and streets. Figures 156 and 157 illustrate these tools.

Concrete sidewalk tools are made in both bronze and iron. Some workmen prefer the bronze tool because it does not rust. Others prefer the iron tool because of the greater durability of iron. The bronze can be hardened, however, by a special process that makes it very durable.

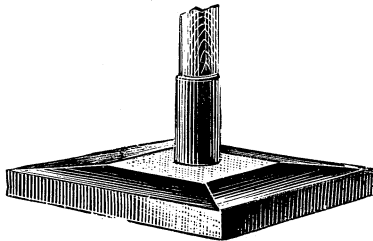


Fig. 151.—Rammer.

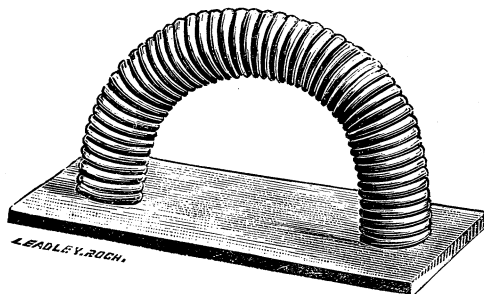


Fig. 152.—Bronze Name Stamp.

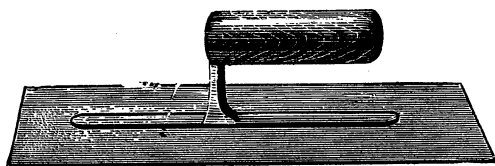


Fig. 153.—Smoothing Trowel.

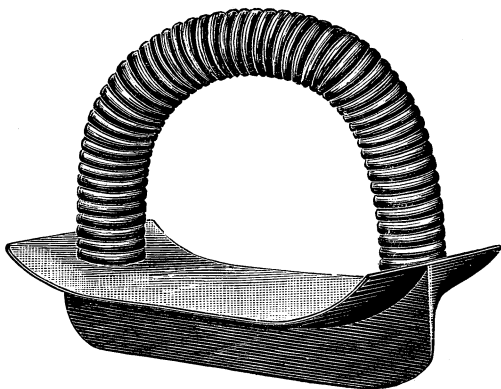


Fig. 154.—Improved Sidewalk Edger.

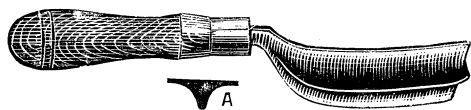


Fig. 155.—Jointing Tool.

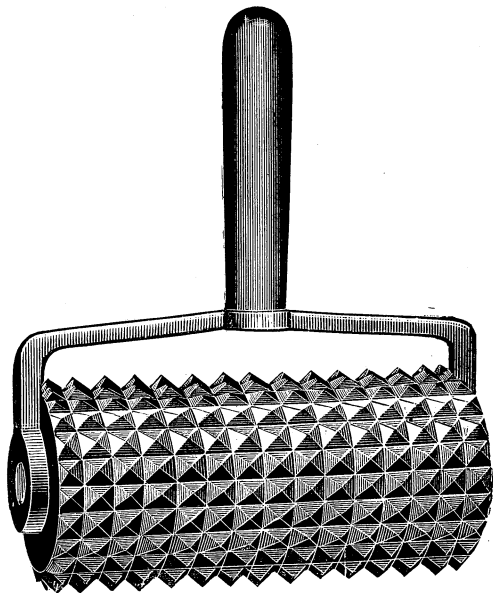


Fig. 156.—Dotting Roller.

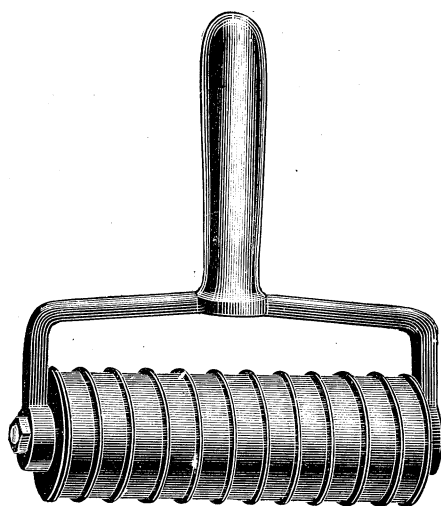


Fig. 157.—Line Roller.

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BULLETIN No. 3.

THE
MANUFACTURE OF HYDRAULIC
CEMENTS,

BY

ALBERT VICTOR BLEININGER, B. Sc.

LETTER OF TRANSMITTAL.

PROF. EDWARD ORTON, JR., *State Geologist*:

DEAR SIR:— In accordance with instructions received from you I herewith transmit a report upon the Manufacture of Hydraulic Cements.

In this report I have endeavored to develop the principles underlying the processes of cement manufacture in such a manner, that the book might be of some value to the cement manufacturer or cement chemist familiar with the nomenclature of technical chemistry.

I am principally indebted to you for the important suggestions and help given me in preparing this report as well as for the constant consideration and courtesy vouchsafed me. Elsewhere I have expressed my appreciation of the assistance given me by others.

Respectfully submitted,

ALBERT VICTOR BLEININGER.

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PREFACE.

The growth of the American cement industry has been phenomenal. Ten years ago the industry showed but a modest beginning, today it represents many millions of capital. The import of foreign cement which formerly was a great item in our cement consumption is becoming more and more insignificant. But the manufacture of Portland cement is destined to assume still greater proportions as the development in new uses of cement grows and as the younger, now purely agricultural states, turn their attention more towards constructive work.

In spite of the rapid growth in the uses of cement it cannot be said that the financial condition of the industry is flourishing at the present time. To some extent this state of affairs is due to the appearance on the market of new plants who in their eagerness to sell their product, lower the price of cement dangerously close to the cost figure. Again the economic superiority of some plants over others is making itself felt, better equipped plants being able to sell their product cheaper or ship it further than more unfortunate concerns, handicapped by unsuitable location, over-capitalization or inferior mechanical equipment. Thus it behooves the industry to study closely the question of location in regard to the winning of the raw materials, the supply of cheap coal and satisfactory shipping facilities. In Ohio the district comprising the southeastern part furnishing cheap raw materials, cheap coal and excellent shipping would seem especially advantageous for the establishment of an extensive cement industry.

More attention might be paid to the quality of the cement turned out than is now being done at numerous cement works at present. This does not mean that American Portland cements are not, per se, as good as the best Portland cements, since the writer could cite a considerable number of American brands which cannot be excelled, but nevertheless it remains a fact that some cement works are not using the best cement composition possible with their raw materials or are neglecting to pay particular attention to the proper fine grinding of the raw mixture.

Another matter deserving more attention is the preparation of particular cements for particular purposes. Thus for use in sea water, for reservoirs containing water charged with carbonic acid, or soluble mineral salts, cements resisting the various destructive agencies should be produced by grinding the clinker with well burnt silicates, like clay, etc. For building blocks and decorative purposes cements low in soluble salts and low in sulphur should be made and the cement manufacturer should

should cater to the demand for white or colored cement mixtures which is constantly growing. In all such colored mixtures the color should be stable and should not injure the cement. In this manner a demand for higher priced cements answering definite purposes could be built up.

The writer realizes full well the many shortcomings of this report, but hopes that this departure from the usual work on cement manufacture may in some measure be justified. It is very gratifying to be able to record parallel with the mechanical development of the American industry an increasing activity in the field of research which has already given us an honorable position among the world's investigators in this field.

In the preparation of this volume the writer wishes to acknowledge gratefully the assistance rendered him by Mr. S. V. Peppel, B. Sc., author of a report on lime sand brick and the limestone resources of Ohio, and Mr. Samuel Torrey Orton, B. Sc., who was an efficient helper during the summer of 1902. For illustrations and electrotypes acknowledgment is due to the Castalia Portland Cement Co., Castalia, Ohio; Henry S. Spackman Engineering Co., Philadelphia, Pa.; The Allis Chalmers Co., Chicago, Ill.; The Kent Mill Co., New York; The Fairbanks Scale Co., New York; The Williams Pulverizer Co., St. Louis, Mo.; The Bradley Pulverizer Co., Boston, Mass., and others. For assistance in preparing illustrations the writer is indebted to Prof. T. E. French and Mr. Carl B. Harrop.

CHAPTER I.

GENERAL CONSIDERATIONS ON THE HYDRAULIC CEMENTS.

The term cement in its present meaning stands for a mortar which hardens in water as well as in air, in distinction from the air mortars, the ordinary lime mortar, plaster and the so-called Sorel cements. Based on this definition, we know four distinct kinds of hydraulic materials which form the basis of all hydraulic mortars. These are:

1. Pozzuolane cements.
2. Hydraulic limes.
3. Roman cement.
4. Portland cement.

All harden by a process of hydration. They all require water for the initial hardening.

1. Pozzuolane cements are the oldest known hydraulic mortars, having been used by the ancients most extensively, especially by the Romans. The Pozzuolane of the ancients, *pulvis puteolis*, consists of a volcanic tufa, of a porous, open-grained structure which, with the slaked lime, produced the wonderfully durable cement used by the Romans for their gigantic aqueducts and hydraulic work of all sorts. Alone, the pozzuolane materials do not produce a cement, the presence of the slaked lime being invariably necessary. The activity of the volcanic materials depends on the presence of soluble silicic acid, or hydrous silicic acid, which readily enters into combination with the lime hydrate. For this reason any material furnishing silicic acid readily available for reaction with a strong base like lime may be used for this purpose. Even dehydrated silicate of alumina, or lightly burnt clay, will react sufficiently to form with lime hydrate a cement, which has been applied practically by mixing brick dust with slaked lime, resulting in a kind of a hydraulic mortar.

A modern kind of artificial pozzuolane has found extensive application, namely, slag cement, which is made from granulated blast furnace slag ground together with dried quicklime or lime hydrate. Blast furnace slag cooled slowly represents an artificial basic rock with but slight hydraulic properties. When granulated, or cooled quickly from the liquid condition by means of cold water, it possesses the characteristics of the true natural pozzuolane, and has considerable "soluble" or available silicic acid, and when intimately mixed with lime hydrate gives rise to a strong hydraulic cement.

2. The hydraulic limes may be considered as being simply impure limestones, consisting of carbonate of lime intimately blended by nature with clay and some sand. The amount of carbonate of calcium and magnesium is invariably more than 70 per cent. When burnt and made up with water, they slake and gradually harden to a compact mass which attains maximum hardness in water. Owing to their self-slaking, pulverization is unnecessary.

3. Roman cements are likewise naturally blended mixtures of calcium and magnesium carbonates, and clay or earthy matter. The carbonates compose from 50 to 70 per cent. of the mass. On burning they form a porous and friable mass which, however, does not slake in water in the lumpy condition, but must be ground to a powder, which is readily accomplished by means of cheap machinery. The clay content of Roman cement is greater than that of hydraulic limes, the percentage being between 50 and 30 per cent. This limit of composition and the fact that it must be ground distinguishes it clearly from the hydraulic limes. The strength of Roman cement is greater than that of hydraulic lime, though inferior to that of the next higher series, the Portland cements.

4. Highest in the scale of usefulness we find the Portland cements, which, unlike the preceding, are purely artificial materials. In chemical composition they range between 59 and 65 per cent. of calcium oxide, the remainder consisting of the ordinary constituents of clay, viz., silica, alumina and iron.

In the artificial preparation of this cement the constituents, lime-carrying material of any kind whatever and clay, are mixed and ground together most intimately and burned to a high temperature so that vitrification ensues. The resulting mass is, as a rule, of a dark color, dense and hard. On grinding it to a powder it shows striking hydraulic properties, exhibiting a high tensile and crushing strength and a high cementing power. Both the intimate grinding of the raw materials and the pulverizing of the hard vitrified cement (clinker) stand for a considerable expenditure of power, while the high temperature to be reached in burning means a large consumption of fuel. It is natural, hence, that this cement should be a higher priced mortar material, whose greater cost of production is, however, balanced by the increased strength, uniformity and regularity of its behavior in use.

In these four classes of hydraulic materials we have thus a chain reaching from the raw mixture of hydrous silicious rocks with hydrated lime to the highly calcareous silicates formed at a high heat, approaching igneous fusion, as in Portland cement. From the low tensile strength and low specific gravity of the pozzuolane cement we rise, through the hydraulic lime and Roman cement, to the great strength and high specific gravity of the Portland cement.

In the pozzuolane class the reaction is brought about at the ordinary temperature, and the weakly acid character of hydrous silicic acid is made use of, while in the burning of the Roman cement the strong acidity of anhydrous silicic acid at higher temperatures is made evident, resulting

in the production of a compound corresponding to the type formula $(2\text{CaO})\text{SiO}_2$. In the Portland cement reaction the burning temperature is raised still more and hence the acidity of the silica is increased, enabling it to combine with more of the base, and we thus obtain a product corresponding to the type of $(3\text{CaO})\text{SiO}_2$. There is no doubt that if a still higher temperature were employed more base could be taken up, chemically and by solution, and a still more complex hydraulic body obtained.

THE CONSTITUENTS OF THE HYDRAULIC COMPOUNDS.

Silicates of lime (or magnesia) constitute the main component of all hydraulic cements of whatever kind. They are, however, invariably associated with alumina or ferric oxide, which either may be assumed to combine with lime, forming aluminates or ferrates of calcium, as in very basic cements, or to enter into the calcium silicate with the formation of a complex calcium-alumina (iron) silicate.

Both the alumina and iron modify the properties of the simple calcium silicates very decidedly; in fact, they may be said to start the hydration reaction, which, without the sesquioxides, would be extremely slow, too slow for practical application. But as the aluminates are also hydraulic in themselves, their hydraulicity is added to that of the silicates and the total strength is thus increased.

In addition to these functions, the alumina and iron decrease the melting point of the compounds, which means, of course, a lower point of vitrification, which is of vital importance in the burning of the highest type of cements.

SILICA AND ITS SALTS.

This highly important compound exists in nature in immense quantities, forming a large part of the earth's crust. It occurs in three principal forms: 1. Crystalline, or glassy, quartz and quartzite. 2. Amorphous, hydrous and anhydrous. 3. Combined in silicate minerals.

It is derived from all of these forms in greater or less degree for use as an ingredient in cements.

Crystalline Silica.—This, in its various modifications, is known as quartz. It is an important constituent of many igneous rocks, and as the silicate minerals of the latter decompose, thus breaking down the rock, the quartz remains unchanged. Its grains, ground down more or less by mechanical abrasion, are removed by running water or wave action, as sand. When deposited in layers and cemented together by various substances like calcium carbonate, ferric hydroxide, etc., they form sandstones. These, in turn, hardened and cemented by still further heat and pressure become quartzite.

The purest forms of quartz crystal are perfectly colorless, having a specific gravity of 2.69, and are very hard. Quartz may be of almost any color, and its structure may be anything from the most perfect crystalline to the decidedly amorphous, as in fused quartz. Quartz is insoluble in all acids, with the exception of hydrofluoric acid. It is attacked, however,

more or less readily, according to the crystallization and size of grain, by caustic potash and soda solutions. In time, finely pulverized quartz unites completely with the caustic bases, forming hydrous silicates of potassium or sodium. When fused with potassium or sodium carbonate it combines readily with these, producing anhydrous silicates, which again are soluble in water.

When quartz is heated to red heat or above, molecular changes take place expressed by peculiar changes in volume, the material expanding, as has been shown by Chatelier, in a seemingly irregular manner.

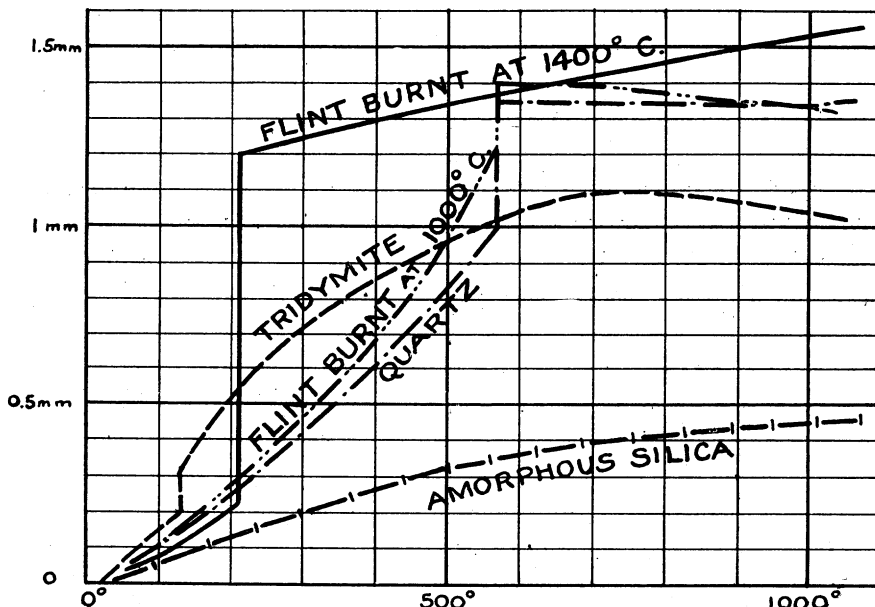


Fig. 1. Chatelier's Curves, showing the expansion of various forms of silica.

These molecular changes, expressed by the expansion, tend to transform the crystalline mass to the non-crystalline or amorphous state. In practical experience this phenomenon is familiarly known in the manufacture of Dinas or silica brick, which are invariably found to increase in volume when exposed to higher temperatures. Likewise in the manufacture of bricks from clay high in sand, which, instead of shrinking, as most clay bricks do, expand in the kiln often to the surprise of the maker. The same fact is applied in the grinding of quartzitic rocks for the pottery industry, which, before being crushed and ground, are calcined and quenched in water while still hot.

But heat assists in bringing about the union of crystalline silica with practically all bases. While the hydrated silicic acid is a most feeble acid, the anhydrous silicon dioxide at higher temperatures becomes the most active and powerful acid, being able to unite with bases in a great number of proportions. In the formation of silicates the physical character of the silica, as well as of the reacting base, is of vital importance in governing the chemical reactions taking place. This refers to the size of

the particles in contact with the basic matter, as well as the crystalline or amorphous condition. While in the discussion of chemical reactions it is always assumed that molecule is in contact with molecule, this ideal condition is never realized except in solutions and fusions. In the manufacture of glass, the sand is ground finely and is intimately mixed with the fluxes, soda and lime. On exposing the mixture to a high temperature the fine particles of silica will be the first to unite with the flux, forming a readily fusible silicate, which later draws the coarser particles into solution. Similarly in preparing artificial silicates from crystalline silica without actual fusion, the first consideration must be fineness of grain. Coarse particles and crystalline fragments are of no value for the reaction. The range of size allowable for the quartz fragments in the preparation of hydraulic mixtures has been examined by the writer in a series of experiments quoted elsewhere. At this stage it suffices to say that quartz grains whose diameter averages more than 0.005 of an inch are practically inert, since their reaction with the basic substance remains only superficial. This question of size is of the utmost importance in practice, since for all artificial cements the quartz must be ground to the required fineness, an operation which means a certain expenditure for power and wear and tear of machinery.

Amorphous Silica.—When quartz is fused with sodium carbonate it dissolves in the latter, forming a sodium silicate readily soluble in water. If we treat the fused mass with water, dissolving it completely, and acidify it we obtain on concentration a precipitate of silicic acid, gelatinous in character. We have thus transformed by fusion the insoluble crystalline silica into the soluble state, for on treating the separated silicic acid with a hot sodium carbonate solution, it will be found to go into solution without difficulty. The colloidal silicic acid, on being brought in contact with hydrated lime, will slowly harden, producing a cement, the substance formed being a hydraulic calcium silicate.

The hydrous silicic acid prepared as above does not correspond to any definite composition, but may be represented by the general formula, $\text{SiO}_2 + x\text{H}_2\text{O}$, the water held chemically being dependent on the conditions of concentration, temperature, acidity, etc., which prevailed during the precipitation of the substance. The chemical activity of the colloid during its hydrous state is proportional to the number of molecules of water fixed chemically, or the amount of water thus held, though silicic acid in no case can ever be considered a strong acid compared with nitric or hydrochloric acids.

Thus we may have the following and many other silicic acids:

H_2SiO_3 , meta-silicic acid, bi-valent.

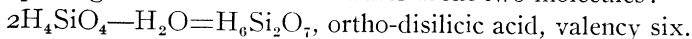
Combining two molecules of meta-silicic acid and imagining one molecule of water split off, we have:

$2\text{H}_2\text{SiO}_3 - \text{H}_2\text{O} = \text{H}_2\text{Si}_2\text{O}_5$, meta-disilicic acid.

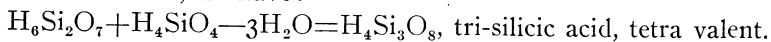
By adding one molecule of water to the meta-silicic acid we obtain further:

$\text{H}_2\text{SiO}_3 + \text{H}_2\text{O} = \text{H}_4\text{SiO}_4$, ortho-silicic acid.

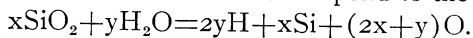
As in the case of the meta-acid, we can obtain from the ortho-silicic acid, by splitting off one molecule of water from two molecules:



Finally, by the union of one molecule of ortho-silicic acid with one molecule of the ortho-disilicic acid, at the same time splitting off three molecules of water, we have:



From these five acids all of the natural silicates can be deduced. They may then be said to form the foundation of the great system of silicates, the basis of the clay, glass and cement industries. But the number of compound silicates theoretically possible is very great, and we may say that the different silicates correspond to the equation,



where x and y are whole numbers.* The number of hydrogen atoms is always divisible by 2, and the number of oxygen atoms is always equal to twice the number of silicon atoms plus half of the number of hydrogen atoms. The following table will illustrate this:

Formula.	Name.
1. SiO_2 ,	Silica, silicon dioxide.
2. H_2SiO_3 ,	Meta-silicic acid, valence 2.
3. H_4SiO_4 ,	Ortho silicic acid, valence 4.
4. $\text{H}_2\text{Si}_2\text{O}_5$,	Meta di-silicic acid, valence 2.
5. $\text{H}_6\text{Si}_2\text{O}_7$,	Ortho di-silicic acid, valence 6.
6. $\text{H}_2\text{Si}_3\text{O}_7$,	di-basic tri-silicic acid, valence 2.
7. $\text{H}_4\text{Si}_3\text{O}_8$,	tri-silicic acid, valence 4.
8. $\text{H}_8\text{Si}_3\text{O}_{10}$,	tri-silicic acid, valence 8.
9. $\text{H}_2\text{Si}_4\text{O}_9$,	tetra-silicic acid, valence 2.
10. $\text{H}_6\text{Si}_4\text{O}_{11}$,	tetra-silicic acid, valence 6.
11. $\text{H}_{10}\text{Si}_4\text{O}_{13}$,	tetra-silicic acid, valence 10.

These hydrous compounds may or may not exist in nature, nor, perhaps, are there anhydrous equivalents produced in the arts, yet the conception of the growth from the acid to the more and more basic compounds must go through the entire scale of silicates and the proper ratios between the RO , R_2O_3 and the acid constituents must be borne strictly in mind. This is illustrated very strikingly by the glasses, and the glazes used in the clay industry which for certain purposes are burnt to different temperatures, each fusing point being fixed by the chemical composition, the ratio of the number of molecules of base to the number of molecules of acid, as well as by the character and number of bases employed. For each one base or one combination of bases combined with silica the fusibility is a function of the base-acid ratio, readily expressed by the oxygen ratio, that is, by the ratio between the number of oxygen atoms in the basic part of the molecule to the number of oxygen atoms in the acid part, as in $\text{CaOSiO}_2(\text{CaSiO}_3)$ where the oxygen ratio

*Dr. Gustav Rauter, Sprechsaal, Vol. 36, p. 462.

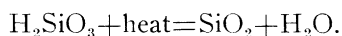
is 1:2, or in $2\text{CaOSiO}_2(\text{Ca}_2\text{SiO}_4)$ where the oxygen ratio (O.R.) is 2:2 or 1:1.

Thus in the case of slag compositions showing an oxygen ratio of 1:1, the resulting slags will be found to be stony in character, melting suddenly and being very liquid, while a blast furnace slag with a ratio of 1:2 is of a more vitreous character and softens gradually.

Roman cements in general correspond to 2CaOSiO_2 or an O.R. of 1:1, while Portland cement approaches closely to 3CaOSiO_2 with an O. R. of 3:2.

We see thus that the character of the many silicates which it is possible to produce depends on whether the composition is placed at one or the other end or the middle of the silicic acid series, giving us clays, glasses, slags or cements.

Although the hydrous silicic acids, given in the table above, lose their chemical water at red heat, being converted back into silica (SiO_2), as shown by the reaction:



the silica under the action of heat will form, according to the amount, number and character of bases and the temperature, salts corresponding to the many possible silicic acids. This fact is repeatedly stated in order to bring out its importance.

As has been said above, the chemical energy of hydrous silicic acid is greater the more water it holds chemically. After the water is expelled, the chemical activity of the acid at the *ordinary temperature* is practically zero, excepting for extremely active bases like potash and soda. It may be said to have become like so much finely ground quartz.

Silica, in the amorphous form, both anhydrous and hydrous, occurs in nature, though not with the abundance and universal distribution which characterizes the crystalline forms. Illustrations of rocks which are used as sources of amorphous silica are chalcedony (which is a mixture of silica and silicic acid), opal, infusorial earth, trass, santorin earth, volcanic ash and pozzuolane. Though not giving rise to cements proper in the modern sense, they furnish an excellent raw material for the manufacture of cements and are especially valuable when used as sand in concrete exposed to sea water, since they unite readily with any uncombined lime. It is in this respect that they have assumed their modern importance in connection with pozzuolane cements.

Combined Silica.—While the elements forming a chemical compound, whether it be a salt of silicic or some other acid, are not viewed by chemists as existing in molecular groups, like SiO_2 or Al_2O_3 , and in that sense it is, therefore, improper to speak of silicates as containing silica, still when these substances are used as the raw materials for new combinations like cements or slags, the latter may be attained with as much certainty and ease as if the silica had been supplied in the form of a pure and separate substance. In fact, silicates are exceptionally valuable for form-

ing new silicate compounds from the fact that when one mineral or compound is broken down by heat or other agency, its ingredients are liberated in the nascent state, and will enter at that time into new combinations with a vigor which they possess under no other circumstances. It is, therefore, advantageous to use natural or artificial silicate minerals as raw materials whenever the composition of such minerals lends itself to the matter in hand. For instance, we could use kaolinite, or silicate of alumina (pure clay), in a cement mixture, because both of its components, silica and alumina, are needed in the cement, but we could not use talc, the corresponding silicate of magnesia, because its magnesia would form an undesirable element in the resultant cement.

Also, while it is advantageous to use silicates, where those containing the proper elements are available, it rarely happens that the proportion in which these elements occur are also such as is needed in the compound to be made. For instance, kaolinite furnishes both silica and alumina to the cement-mix to which it is added, but it can be used in limited quantities only, because its proportions of alumina are high and the silica relatively low. If enough were used to bring in all the silica desired, the resultant cement would be overloaded with alumina. Thus there is this obstacle to the free use of the silicates in producing new silicate compounds, and it is, therefore, generally necessary to obtain the desired composition by mixture of different silicates or more commonly by supplying the extra silica needed in one of its free or uncombined forms.

ALUMINA AND FERRIC OXIDE.

We have now discussed the various sources of silica, the crystalline, amorphous and combined, and have shown how the kind of silica influences the silicate reaction and how complex silicates are built up in the heat reactions with which we are dealing, based on the conception of the hydrous polysilicic acids. But silicates of calcium oxide or magnesium oxide alone would not do the work required of mortars. Of the great numbers of such silicates prepared by the writer, none of them showed the strength of even weak cements, but remained soft and friable; in water they often crumbled, and yet by the very preponderance of the silica in cements the calcium silicate must be the main hydraulic agent. But it is evident that the alumina must play an important role in causing the hydration reaction to take place in the manner which we know in cements.

In order to show how alumina affects the hydration of cements it is perhaps best to indicate how alumina behaves when united with calcium oxide alone. Prof. Zulkowski*, thus found that a mixture of calcium oxide and alumina corresponding to the formula CaAl_2O_3 , burnt for eight hours when mixed with water, set in two minutes and hardened to a very hard mass over night; in three months it became so hard that it could hardly be scratched with a knife. A mixture of the formula $2\text{CaAl}_2\text{O}_3$ heated to vitrification also hardened with great rapidity in

*Sonderabdruck aus "*Die Chemische Industrie*," 1901.

two to three minutes and assumed an extraordinary hardness after being in water for three months. We see hence that the alumina-lime compounds play an important role in the economy of the cementing process. They accelerate the reaction and contribute strength.

Thus the American investigators, S. B. and W. B. Newberry*, obtained practically the same result. The mixture $2\text{CaOAl}_2\text{O}_3$, when made to a mortar with water, set very rapidly in a few seconds and became extremely hard.

The experimental work in the investigation of the alumina-lime compounds has been carried on by many chemists like Winkler, Chatelier, Michaelis, Newberry, Rebuffat and others.

As we have seen, the most readily available source of silica for cement making is clay which invariably introduces a certain amount of alumina with every part of silica, it being, as we know, an aluminum silicate. If we were to take a pure clay, kaolinite, and mix it with enough lime to make, say, a bisilicate and a bicalcium aluminate we would obtain on burning a hydraulic cement which would harden well, but too rapidly. The rapidity of setting of this cement is due to the high content of alumina and is a source of danger, as the cement in practical use would show a dangerous tendency of cracking. We see thus plainly that the alumina must be kept low so as to keep the cement within safe limits, but it must always be present.

Zulkowski prepared a cement from Zettlitz kaolin ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) corresponding to the formula $2(2\text{CaOSiO}_2) (2\text{CaOAl}_2\text{O}_3)$. On burning this mixture to vitrification a white porcelain-like body was produced which, when powdered and mixed with water, set in fifteen minutes. After ninety minutes the cement became extremely hard and after a few months it was found to be still harder. Zulkowsky did not test this cement for constancy of volume. By the addition of quartz he prepared other white cements with the same lime-silica ratio (2CaOSiO_2), which were all excellent cements.

These examples have thus shown clearly the necessity of having alumina present in cements. Just what the exact chemical function of alumina is cannot be discussed here at this stage, but the discussion must be postponed to a later part of this work.

The Function of Ferric Oxide.—Chemically, iron is the natural substitute of aluminum, which is shown by the fact that it forms different hydrates corresponding to the various hydrates of aluminum. The first conclusion would hence be that ferric oxide behaves similarly to alumina when combined with lime, or with lime and silica. Many investigators have searched into this relation with different results and conclusions.

Zulkowsky again has made experiments in this direction in the most careful manner, and as his results check with those of the most noted

*The Constitution of Hydraulic Cements, *Journal Society Chemical Industry*, November 1897.

investigators, they may be selected as representing the characteristic behavior of ferric oxide.

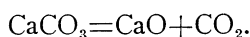
On burning the mixture CaOFe_2O_3 in the Seger furnace till partially fused it assumed a graphite-like appearance, and when ground and mixed with water it formed a pat of a fine mahogany-like color. It set in four hours. After five hours more it was hard enough to be placed in water. After several months the pats became quite hard, but did not show as much strength as the corresponding alumina compound. The mixture $(2\text{CaO})\text{Fe}_2\text{O}_3$, burnt to softening, which took place at a white heat, showed a decided crystalline structure. After grinding and making up with water the pats set in fifteen minutes and in one to two hours had become quite solid and hard. After one week in water they softened somewhat and lost their original strength. When dried in a dessicator they became harder again, but did not reach the hardness of the corresponding alumina compound. More favorable results were obtained with impure materials, that is, with reagents containing some silica and alumina.

We can say, therefore, that the iron-lime compounds are very similar to the alumina-lime products, though much more feeble in their hydraulic reaction. One function in which iron is more effective is the greater fusibility produced by it. While a lime silicate like $(3\text{CaO})\text{SiO}_2$ is practically infusible excepting in the electric furnace and the oxy-hydrogen blowpipe, it is at once rendered more fusible by the addition of alumina and much more fusible by adding ferric oxide. This is observed quite strikingly in using as the clay base a pure clay, like kaolin, or an impure variety containing more or less iron. Only by the presence of iron is it possible to burn Portland cement at commercially feasible temperatures. In addition the oxides of iron seem to counteract the phenomenon known to the cement men as "dusting," and of late the surprising resisting power of ferruginous cements to the action of sea water has aroused general attention.

LIME.

This important material, which constitutes the greatly preponderating ingredient of all hydraulic cements, occurs in nature in enormous quantities, chiefly as calcium carbonate, from the almost chemically pure form of calcite and aragonite, in various degrees of purity, down to the loamy and impure marl clays. Pure calcium carbonate consists of 56 parts calcium oxide and 44 of carbon dioxide, which begins to be expelled at about 600°C ., the evolution of the gas being completed at 1040°C . in all limestones. The harder, more dense and crystalline the carbonate of lime is the slower and more reluctantly will the carbon dioxide be evolved. By the presence of silica or silicate of alumina the decomposition of the carbonate is accelerated, and hence more impure limestones are easily overburnt, as the practical lime burner says.

Calcium carbonate is dimorphous, crystallizing as calcspar in the hexagonal and as aragonite in the rhombic system. Calcium carbonate is nearly insoluble in water, 1,000 grams of water dissolving .0018 gram of the compound, but it is more soluble in water containing carbon dioxide; 1,000 grams of water charged with this gas will dissolve, at 0°C., 0.7 gram of calcium carbonate; by increasing the pressure 3 grams of the carbonate may be dissolved. This calcium salt is readily decomposed by inorganic and even weak organic acids with the evolution of carbon dioxide. When exposed to higher temperatures the calcium carbonate is decomposed according to the reaction:



On enclosing a piece of calcium carbonate in a tube and connecting the latter with a mercury manometer it is found that for every temperature the evolution of the carbonic acid gas remains stationary at a certain pressure, no more calcium carbonate being decomposed. This was shown experimentally by Le Chatelier,* who thus determined the dissociation tensions of calcium carbonate for a number of temperatures, which are shown in the accompanying table:

Dissociation of Calcium Carbonate.

Temperature.	Pressure.	Temperature.	Pressure.
547° C.	27 mm. Mercury.	745° C.	289 mm. Mercury.
610 "	46 " "	810 "	678 " "
625 "	56 " "	812 "	753 " "
740 "	205 " "	865 "	1,333 " "

The reaction is a reversible one; that is, carbon dioxide is reabsorbed as soon as the tension of the gas approaches the dissociation tension at the given temperature and calcium carbonate is again formed. This point is well illustrated in limekilns where it is observed that when the draft of the kiln is sluggish and the temperature low the calcium oxide, being surrounded by the carbon dioxide, reverts to calcium carbonate.

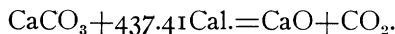
The decomposition of calcium carbonate is accelerated by the presence of steam, so that the burning temperature is reduced greatly. Professor Herzfeld has made extensive experiments with the use of superheated steam and has proven that it affords an excellent means of producing a high grade porous calcium oxide.

*Compt. rend. 102 1233 (1886.)

His results are given in the following table:

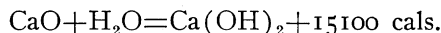
Temperature.	500°C.	650°C.	680°C.	790°C.
Per cent. of Calcium Oxide in limestone burnt in steam.....	0	7%	23%	100%
Per cent. of Calcium Oxide in limestone burnt in air.....	0	0	0	37%

The impurities contained in limestone accelerate the rate of decomposition, this being especially true of silica. At 1000° C. 8 per cent. of silica causes the lime to be overburnt owing to the formation of a calcium silicate. The higher the temperatures the greater will be the effect of any silica present. The same thing may be said of alumina and iron, though these are less energetic in their behavior. Pure lime burnt from calcium nitrate at 1300° C. hydrates extremely slowly; burnt at 1600° C., the calcium oxide is crystalline and can be hydrated, but not slaked, showing hydraulic properties. Somewhat below 1600° C. it forms a porcelain-like mass of great density. In the electric furnace calcium oxide sublimes at a temperature corresponding to about 3000° C., melting and boiling between the electrodes. The condensed sublimed matter forms beautiful crystals of calcium oxide. The thermal reaction of the decomposition of calcium carbonate is as follows:



or 1 gram of calcium carbonate requires 437.4 gram calories for its decomposition. One pound of the carbonate of lime would thus require the heat of 0.06 pound of average Ohio coal, taking 7,000 calories as the calorific value of the fuel.

The calcium oxide, as we know, on being brought in contact with water eagerly combines with the latter, forming calcium hydrate according to the reaction:



This is seen to be an exothermic reaction, one gram of the calcium oxide evolving 269.6 calories. The hydration is accompanied by an increase in volume. While the specific gravity of the calcium oxide varies from 3.08 to 3.18, that of the hydrate is 2.078. The increase in apparent volume of the oxide on being changed to the hydrate is about 3½ times the original volume if just enough water is added.

This explains the injurious action of lime in cement or bricks and other clay ware, the body containing the lime being destroyed by the hydration as soon as water is being absorbed. The increase in the volume of the oxide depends to a great extent on the manner of slaking; that is, on the amount of water used. Lime hydrate is decomposed into calcium

oxide and water at red heat. Its solubility in water at the ordinary temperature is 0.14 parts, at 100° C. half of this amount. Lime is dissolved more readily by a sugar solution, or glycerine, or an alcoholic iodine solution.

Calcium oxide absorbs carbonic acid eagerly, especially at higher temperatures. On heating calcium oxide in a bulb to redness, removing the lamp and conducting carbon dioxide into the bulb in a strong current, it will be found that the lime becomes red hot in a few seconds, continuing to glow for fifteen minutes owing to the energetic absorption of the carbonic acid.*

All these facts tend to show that lime is a very powerful base, combining with acids with the greatest ease. Not only higher temperature, but also lower ones may bring about the union of silica and lime. When a mixture of quartz and lime hydrate is exposed to steam at a pressure of about 120 pounds to the square inch a reaction between them takes place; a hard, artificial sandstone is produced. This is the basis of the sand-lime brick industry.

The varieties of rocks and minerals which are used as a source of carbonate of calcium will be discussed in the next chapter. Beside the carbonate, there are a few other lime compounds having a more or less important use in this same connection.

Gypsum, composed of one molecule of calcium sulphate and two molecules of water, is a possible but not a probable source. Its value for other purposes is too great to make it applicable for cement-making; besides, it would offer difficulties in manufacture which would be hard to overcome. The complete expulsion of the sulphuric acid would be a difficult task and the liability of retaining sulphur in some shape in the cement too great. Gypsum is used in the cement industry, but not in direct connection with the cement burning itself.

Though slag from blast furnaces is a source of calcium oxide, in a way, it is united with so much silica and alumina that it must be considered as furnishing silica rather than the base.

In some processes of the chemical industries calcareous waste products may be used for the manufacture of cement. This applies especially to the manufacture of soda by the Solvay process, where calcium chloride becomes available for cement making in large quantities. This material is chemically well suited for the purpose, since the chlorine is expelled with comparative ease.

Dolomite.—The double carbonate of calcium and magnesium is known as dolomite. Its percentage composition when pure is 54.35 per cent. calcium carbonate and 45.65 per cent. magnesium carbonate.

Like limestone, it is subject to the same variations in composition and physical properties, as we have hard, compact dolomites as well as

*Raoult, *Compt. rend.* 92, pp. 189 and 1111.

soft, marl-like dolomitic materials. But the relative proportions between the magnesium and calcium carbonate vary greatly, so that we start from practically all calcium carbonate to the dolomitic proportions 54.35 calcium to 45.65 per cent. magnesium carbonate. The specific gravity of dolomite is from 2.8 to 2.95; the hardness of the compact rock is greater than that of limestone and it is distinguished from the latter in that it is much less readily soluble in cold hydrochloric acid. Some of the hard dolomites show a distinct fissured structure. Sometimes dolomite is found in beds formed by direct deposition as the precipitate from saturated water, or it may be found replacing original deposits of limestone. As a cement material it is not promising, since it gives rise to two silicates (of lime and magnesia) which have different rates of hydration and which hence interfere with each other in the hardening process, unless the burning took place at a low temperature not over 1000° C. In nature we find dolomitic hydraulic materials in the form of the natural cement rocks, like the Rosendale, Louisville, Utica and Milwaukee. But all of these must be burnt at a low temperature, at which not all of the calcium carbonate has been decomposed.

MAGNESIA.

This substance is chiefly derived from magnesite, magnesium carbonate, which is closely analogous to calcium carbonate in all its properties. It crystallizes as rhombohedral crystals, isomorphous with calcite. Its decomposition, however, takes place at a considerably lower temperature than that of calcite, carbon dioxide being evolved at a lively rate at about 500° C. Magnesium exhibits a great tendency to form basic and hydrated carbonates, whose compositions vary with the conditions of precipitation. On heating magnesium solutions to higher temperatures, subjecting them to higher pressures or evaporating them to dryness, the normal carbonate is formed.

The mineral hydromagnesite is a basic carbonate of the composition $3\text{MgCO}_3\text{Mg}(\text{OH})_2 \cdot 3\text{H}_2\text{O}$. Artificially prepared magnesium carbonates are usually bulky, very light precipitates. From boiling solutions a denser basic carbonate is obtained than from cold ones. In nature we find magnesium carbonate as a dense, usually white, mineral. On burning this first loses its carbon dioxide and begins to shrink in volume quite decidedly, continuing to do so up to very high temperatures.

Magnesium oxide slakes on contact with water and shows some increase in volume, but this increase is much less than that of the calcium oxide converted into calcium hydroxide.

The hydration of magnesium oxide is itself associated with hydraulic activity; that is, magnesium oxide prepared at a low temperature when made up with water will harden and form a tolerably strong cement, as was found to be the case by Deville and others. Magnesium silicates and aluminates show decided hydraulic properties. Thus Fuchs was able to

produce a very hard cement by burning talc at a very high temperature. Lieven also claims to have produced well hardening cements by igniting a mixture of one equivalent silica with one equivalent of magnesia. Rivot* says that magnesium silicates behave similarly to the lime compounds, while Held was not able to produce any hydraulic compounds from magnesia minerals and artificially prepared silicates. Kawalewsky again reports on vitrified magnesia cements which after ten years were still found to be sound and which had shown high tensile strengths. Zulkowski prepared the dimagnesium silicate and found it to show hydraulic properties, setting in two hours to a hard, earthy mass. After two months in water it attained moderate hardness.

**S. B. and W. B. Newberry came to the conclusion that magnesia shows no hydraulic properties when heated with silica, alumina or clay, and says that it probably plays no part in the cement reaction. Hence these investigators claim that magnesia cannot replace lime in cement mixtures.

Sorel Reaction.—Magnesium oxide burnt at a low temperature, mixed with solutions of salts, like magnesium chloride or calcium chloride, produces extremely hard though usually slow-setting cements, used to some extent in fastening brass to glass as in lamps, laying floor or wall tiles, or similar purposes. Cements of this type are called Sorel cements and include also similar mixtures, like calcium oxide and calcium sulphate, anhydrous gypsum made up with a solution containing Glauber's salt or potassium sulphate and others. The last named mixture even is hydraulic in character and is extensively used for making floors in place of Portland cement being known as Estrich or Mack's Cement. The Sorel reaction depends on the formation of basic double salts, as a rule very insoluble in character. Kosmann† attributes the formation of these compounds to the so-called chemical residual energy. Though the chemical valency of many compounds is satisfied they have not yet lost all chemical activity, in fact, many of the so-called neutral salts may be considered as unsatisfied compounds. This seems to be shown by their thermo-chemical behavior. It is found that outside of the heat produced by the combination of acids and bases there is still some heat left which represents a certain chemical energy. This heat is called by investigators the residual chemical energy which enables the so-called neutral salts to take up water in chemical combination as well as to add, in place of water, salts or oxides to the molecular structure. All of the salts of strong acids and bases are caustic in nature, which is shown by their tendency to take water from other salts. Examples of this kind are cupric sulphate, lead chloride, cupric chloride, sodium carbonate and many others. This caus-

* *Wagner's Jahresbericht*, 1856, p. 131

** *The Constitution of Hydraulic Cements. Journal Society Chem. Industry*, Nov. 1897.

† *Transactions, Deutscher Verein fuer Ton, Cement und Kalk-Industrie*, 1900.

tic effect is due to the residual chemical energy. Basic salts are produced simply by the substitution of oxides in the place of water taken up. Thus lead chloride takes up two molecules of water: $\text{PbCl}_2\text{H}_2(\text{OH})_2$, while magnesium chloride unites with six molecules of water: $\text{MgCl}_2\text{H}_6(\text{OH})_6$.

The chemical energy shown by the hydration of these compounds may take the form of uniting with as many molecules of another compound as it has taken up water; or, the water may be replaced by an oxide like magnesium oxide, calcium or barium oxide, so that there is produced a basic compound like MgCl_2MgO , this being the formula of the Sorel cement, named after the inventor, who made the discovery in 1867.

This extraordinary ability of such compounds to form basic salts Kosmann illustrates by the many natural compounds existing which closely follow the formula of basic salts. He mentions:

Hydrous Magnesite	$3\text{MgCO}_3\text{Mg}(\text{OH})_2\cdot 3\text{H}_2\text{O}$
Malachite	$\text{CuCO}_3\text{Cu}(\text{OH})_2$
Basic zinc carbonate	$\text{ZnCO}_3\cdot 2\text{Zn}(\text{OH})_2$
Clay	$\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2\cdot 2\text{H}_2\text{O}$
Serpentine	$3\text{MgO}\cdot 2\text{SiO}_2\cdot 2\text{H}_2\text{O}$
Willamite	$\text{ZnSiO}_3\cdot \text{ZnO}$

Magnesite as such is at present not available in large quantities in the United States, it being imported chiefly from Greece and Styria. Hence its cost would be too great for production on a large scale at this time. It owes its importance to its refractoriness, being a valuable basic heat-resisting material. Its drawbacks in this connection, however, are its great brittleness and its tendency to crumble when exposed to temperature fluctuations as well as its marked conductivity of heat.

CHAPTER II.

RAW MATERIALS OF THE CEMENT INDUSTRY.

In this chapter will be taken up the various raw materials of the four kinds of hydraulic cements, taken in the order of the classification adopted, which brings the highest class of cements as the last and most complex of the series.

RAW MATERIALS FOR POZZUOLANE CEMENT.

In the oldest type of hydraulic pozzuolane materials we have as the main constituent a substance containing hydrous silicic acid which on the simple addition of slaked lime becomes a hydraulic cement. These materials show extreme variety in composition and physical behavior. Modern metallurgical processes furnish us in addition artificial pozzuolanes which are finding application as valuable cement materials. We can thus distinguish natural and artificial pozzuolanes.

We have no natural pozzuolanes in Ohio, and yet they deserve some discussion due to the fact that as an addition to Portland cement for work in sea water they have shown valuable properties. Owing to the great solvent action of sea water on concrete, the question of the life of cement work has become an extremely important one. There is no doubt but that some concrete work exposed to sea water has suffered considerably, and the knowledge of the fact has caused apprehension on the part of engineers, many of whom still look with suspicion upon cement as a proper material to be subjected to the action of sea water. Since the capital involved in concrete construction of this kind is enormous, it has become a vital task to users as well as sellers of cement to study the behavior of this material under various conditions and to devise means of improving it when necessary.

The principal natural pozzuolanes are pozzuolane proper, trass and santorin-earth. All of these when mixed with slaked lime harden and form a hydraulic mortar.

The pozzuolane proper is a hydrous, volcanic, porous rock whose specific gravity is from 2.3 to 2.55, found in Italy, especially near the

Vesuvius and at Bacoli, as well as at Montenuova. It is partly soluble in hydrochloric acid. The composition of two typical pozzuolanes is:

	Per cents.	
	I*	II**
Silica.....	47.85	73.00
Alumina.....	17.35	11.90
Ferric Oxide.....	9.75	1.55
Lime.....	10.00	0.65
Magnesia.....	3.90	.....
Loss on ignition.....	6.10	4.30
Alkalies, etc.....	4.70	8.45
Silica soluble in caustic potash	15.70	12.40
Silica soluble in sodium carbonate solution...	2.30	2.00

*Feichtinger, *Chemische Technologie der Moertelmaterialien*.

**R. Feret, *Tonindustrie Ztg.* No. 15, Vol. 25.

No. I is an Italian pozzuolane. No. II is found in Nebraska. Typical analyses of trass and santorin earth are as follows:

	Per cents.	
	Trass.	Santorin Earth.
Silica.....	59.75	65.55
Alumina.....	18.05	14.60
Ferric Oxide.....	3.70	4.10
Lime.....	1.90	3.70
Magnesia.....	0.65	0.95
Loss on ignition.....	7.00	4.25
Alkalies, etc.....	8.85	6.50
Silica soluble in caustic potash.....	17.30	14.00
Silica soluble in sodium carbonate solution...	1.00	2.00

*R. Feret, *Ton. Ztg.* No. 15, Vol. 25.

Trass also is a kind of volcanic tufa, it being consolidated volcanic dust which has been subjected to the action of pressure and water. It is found in large quantities in the Rhine province, Germany, the top layers being loose in structure, the lower rock-like. Trass, like pozzuolane, is partly soluble in hydrochloric acid and contains water of hydration.

Santorin-earth is found on the Island of Santorin and is likewise a kind of volcanic material, like pumice-stone, but is softer than the two preceding materials. It differs in its high content of free amorphous silica; it is not so easily decomposed by acids and does not gelatinize. About one-fifth of the Santorin-earth is supposed to be pumice stone.

ARTIFICIAL POZZUOLANES.

Similar to the natural pozzuolane rock products, we can produce such materials artificially, and the two most important pozzuolane substances of this kind are the slags and the dehydrated clays.

Slags.—The slags used for this purpose are the waste products of the blast furnaces smelting iron from its ores. Slags from the refining of pig iron, or the manufacture of steel, or from the manufacture of other metals than iron are not used.

The slag as it leaves the furnace is converted into a true pozzuolane by being quenched in cold water while still in the hot liquid condition. But not every slag is available for hydraulic purposes. Several factors, of which the most important is the composition, govern the properties of the material. Tetmayer* in his extensive and thorough examination of the subject says the following in regard to the composition of suitable slags:

“The hydraulic activity of a slag depends in the first place on its basic character expressed sufficiently by the ratio of the lime to the silica. All slags corresponding to a ratio of

$$\text{CaO} : \text{SiO}_2 < 1.00$$

are not suitable for cement making. The most favorable ratio of lime to silica and to alumina is approximately

$$\% \text{CaO} : \% \text{SiO}_2 : \% \text{Al}_2\text{O}_3 = 46 : 30 : 16 = 1.00 : 0.65 : 0.35 \quad \text{or} \quad \text{CaO} : \text{SiO}_2 + \text{Al}_2\text{O}_3 = 1.00 : 1.00.$$

Magnesia is not a desirable constituent of slags and should be as low as possible. A high content of sulphur is very objectionable and for best results the content of sulphur should not be more than 1.25 per cent. With the same composition the greenish gray, more glassy, slag from gray iron is to be preferred to the yellowish foamy material. In the granulating process this slag should be as thin liquid as possible and the water used in quenching quite cold.

*Resultate Spezieller Untersuchungen auf dem Gebiete der Hydraulischen Bindemittel
page 152.

Blast furnace slags are bodies closely akin to glasses and might be considered alloys in character. It is, of course, evident that the composition of the slag is dependent on the composition of the ore as well as on the kind of pig iron it is desired to produce. If the ores used are uniform in character, the slag produced will also be regular in composition as long as the same grade of iron is being made. It is obvious that an ore high in silica will require more limestone for fusion than one lower in this constituent; an increase in the sulphur or phosphorus in the ore will also necessitate an increase in the lime content of the slag. The foundryman in trying to smelt iron cheaply and yet maintain a good quality is certain to make a slag of a variable composition. Since the slag is the by-product, it is of importance only so far as its composition and fluidity affect the working of the furnace and the quality of the iron. Some limitations are met, however, in the fluctuation of the slag, as it will not melt and flow freely, if its composition departs too far from the usual range. Thus it is often impossible to remove all the impurities, sulphur and phosphorus from the iron, as the high content of calcium necessary would make the resulting slag too refractory. If the slag is to be used for the manufacture of slag cement, proper allowance must be made for the fluctuations in the composition resulting from the variations in the composition of the ore. Slag of improper composition should be rejected for the making of pozzuolane cement, though it may be used for the manufacture of slag brick. The rules of Prof. Tetmayer, given above, which he has deduced from a great number of analyses and experiments, will serve as a guide for the selection of a slag.

In the tables on pages 45 and 46 are given the analyses of a number of European blast furnace slags which were made the subject of an investigation pertaining to slag cements by Prof. L. Tetmayer,* excepting No. 21.

Prof. Tetmayer also made an elaborate series of tests with these slags in the granulated condition by grinding them together with various amounts of hydrated lime and testing them for tensile and crushing strengths. These results, representing mixtures with 15 per cent. of lime, are plotted in the accompanying curve, figure No. 2.

These results seem to show that the general tendency of the slags is to correspond to the Tetmayer ratio, although this fact is brought out by no means sharply. We must remember, however, that other factors enter into the resulting strength of slag cements, such as the degree of liquidity, the degree of granulation of the slag, etc. Until additional experimental data are collected the results of Tetmayer must, as a whole, be accepted. Prost and Mahon take exception to his limits with reference to the alumina, as they have obtained good results with higher alumina contents.

*L. Tetmayer: *Resultate Specieller Untersuchungen Hydraulischer Bindemittel*, Zurich 1897.

Number.	Per cents of Ingredients.							
	Silica.	Alumina.	Ferrous Oxide.	Manganous Oxide.	Calcium Oxide.	Magnesium Oxide.	Calcium Sulphate.	Calcium Sulphide.
1	35.07	4.99	1.13	7.63	40.73	4.28	1.72	2.18
2	39.59	9.07	0.64	5.12	34.89	11.66	.....	2.28
3	27.31	22.40	1.36	.....	47.00	0.42	0.12	1.39
4	34.33	11.01	1.73	.....	49.78	0.99	.....	2.16
5	27.98	19.69	0.30	.....	44.64	4.76	0.03	2.61
6	33.16	11.93	1.47	.....	48.63	1.03	.....	3.79
7	39.95	14.98	0.34	.....	40.46	1.62	0.24	1.99
8	34.77	7.71	0.70	0.34	49.17	2.02	0.65	2.29
9	30.55	13.68	0.43	0.34	48.03	3.27	0.48	3.20
10	35.11	17.43	0.24	2.61	39.76	4.32	0.27	2.28
11	32.51	13.91	0.48	0.60	44.75	2.20	0.64	4.90
12	32.79	18.25	0.82	2.77	39.16	4.33	0.51	1.46
13	30.81	17.55	0.60	2.43	42.30	4.35	0.29	1.77
14	29.91	20.49	0.84	1.31	39.83	3.31	0.96	1.99
15	27.86	22.05	1.28	0.50	39.17	4.23	0.10	2.86
16	28.33	13.81	1.44	0.50	46.66	5.44	.....	3.82
17	31.90	18.40	0.99	2.27	40.27	4.46	0.14	1.64
18	30.49	17.15	0.70	1.65	44.29	4.48	.....	1.11
19	32.17	17.84	0.74	.....	43.79	2.19	.....	2.27
20	28.73	22.87	0.96	.....	39.94	4.51	0.16	3.23
21	32.20	15.50	.....	.....	48.14	2.27	.....	.....

$\frac{\% \text{CaO}}{\% \text{SiO}_2}$	$\frac{\% \text{CaO} : \% \text{SiO}_2}{\% \text{Al}_2\text{O}_3}$	Oxygen Ratio (Molecular) $\text{CaO} : \text{Al}_2\text{O}_3 : \text{SiO}_2$	Specific Gravity.	Loss on Ignition.	Remarks.	Number.
1.16	1 : 0.86 : 0.12	1.25 : 0.25 : 2	3.09	0.59		1
1.07	1 : 0.93 : 0.26	1.15 : 0.48 : 2	3.17	2.80		2
1.72	1 : 0.58 : 0.48	1.84 : 1.44 : 2	2.88	0.08		3
1.45	1 : 0.69 : 0.22	1.59 : 0.57 : 2	2.96	0.90		4
1.60	1 : 0.63 : 0.44	1.70 : 1.23 : 2	2.94	0.05		5
1.47	1 : 0.68 : 0.25	1.58 : 0.56 : 2	2.90	2.09		6
1.01	1 : 0.99 : 0.37	1.08 : 0.66 : 2	2.85	0.41		7
1.41	1 : 0.71 : 0.16	1.51 : 0.39 : 2	2.94	1.94		8
1.58	1 : 0.64 : 0.28	1.67 : 0.78 : 2	2.89	2.79		9
1.20	1 : 0.83 : 0.44	1.29 : 0.93 : 2	2.81	5.05		10
1.38	1 : 0.73 : 0.31	1.47 : 0.75 : 2	2.85	3.17		11
1.19	1 : 0.84 : 0.47	1.28 : 0.99 : 2	2.89	0.25		12
1.37	1 : 0.73 : 0.41	1.47 : 1.14 : 2	2.92	0.42		13
1.33	1 : 0.75 : 0.51	1.43 : 1.20 : 2	2.89	1.06		14
1.40	1 : 0.71 : 0.56	1.51 : 1.38 : 2	2.93	0.31		15
1.65	1 : 0.61 : 0.30	1.76 : 0.87 : 2	2.94	3.08		16
1.26	1 : 0.79 : 0.46	1.36 : 1.02 : 2	2.87	0.37		17
1.45	1 : 0.69 : 0.39	1.55 : 0.99 : 2	2.91	0.58		18
1.36	1 : 0.73 : 0.41	1.47 : 0.99 : 2	2.91	0.25		19
1.36	1 : 0.74 : 0.59	1.45 : 1.41 : 2	2.88	0.48		20
1.49	1 : 0.67 : 0.32	1.62 : 0.85 : 2			American cement slag	21

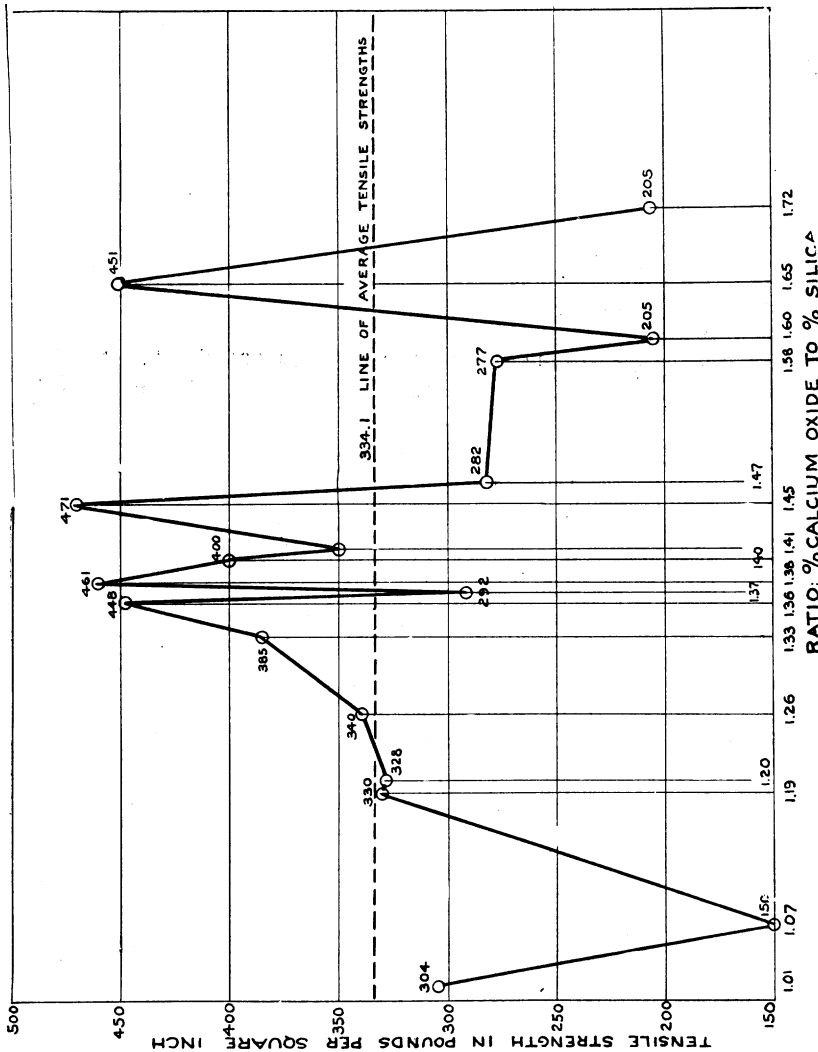


Fig. 2. Tetmayer's Curve, showing the tensile strength of various granulated slags, with 15 per cent. of calcium hydrate tested after 28 days in water.

Principles of Slag Formation.—The formation of slags has received great attention for a long time by metallurgical chemists. The principles of their formation and the methods used in their study are identical or closely analogous to the formation and study of cement silicates, and for that reason the following resume has been prepared.

Beside the proper chemical composition of the slag which is necessary to remove the detrimental constituents of the ore by fusion the melting point of the slag is of extreme importance as well as the degree of liquidity on fusion.

For purposes of comparison it might prove of value to marshal the different possible silicates in a table so that their relations to each other may be understood in which "RO" stands, in general, for any base, like calcium oxide, magnesium oxide, barium oxide, etc.:

Name of Silicate.	Molecular Formula.	Oxygen Ratio.
Tri-silicate.....	$2RO \ 3SiO_2$	$2 : 6 = 1 : 3$
Bi-silicate.....	$RO \ SiO_2$	$1 : 2$
Sesqui-silicate.....	$4RO \ 3SiO_2$	$4 : 6 = 2 : 3$
Singulo-silicate.....	$2RO \ SiO_2$	$2 : 2 = 1 : 1$
Subsilicate.....	$3RO \ SiO_2$	$3 : 2$

We observe that the names of the silicates are derived from the oxygen ratio which has been universally accepted as the metallurgical nomenclature.

According to Ledebur, the bi-silicate of calcium is the most fusible compound, the temperature rising with an increase in lime or silica. The singulo and tri-silicates fuse only at a very high temperature, while the subsilicate is infusible excepting in the electric furnace and in the oxy-hydrogen flame. The magnesium silicates are all difficult to fuse and do not show such decided differences in their melting points as the calcium silicates. Of the lime-magnesia silicates (one molecule of CaO to one molecule of MgO) the bi-silicate is, according to Berthier, the most fusible one, while the tri-silicate is the most infusible.

The presence of alumina modifies the melting point of a slag considerably, the most fusible lime-alumina silicate being, according to Bodemann*, a bi-silicate approximately $4CaSiO_3 + Al_2Si_2O_9$. Berthier found that all lime-alumina silicates are most fusible when the amount of alumina is about one-third of that of lime, by weight, it being equal to 1 equivalent of alumina for 6 equivalents of lime or 102 parts by weight of alumina to 336 parts of calcium oxide.

The same investigator found that an increase in the lime content causes the melting point to rise only very gradually, but rapidly as soon as the alumina is increased, so that silicates with the molecular ratio of 1 equivalent of alumina to 3 equivalents of calcium oxide are still fusible, while with a ratio of 2 alumina to 3 of lime the slags are almost infusible.

Beside the melting point proper, we must consider the degree of liquidity or the viscosity of the slag on melting. The slags melting at the lowest temperatures are not always the most liquid ones. The slower the transformation from the solid to the liquid condition the more viscous and "tough-liquid" will the slag be. Slags high in silica and also those high in magnesia or alumina show this property quite strongly and hence are as unfit for the purposes of iron manufacture as slags with too high a melting point. In a slag of proper composition the fusion takes place

*Bodemann, Probirkunst, p. 251.

suddenly and the resulting liquid slag is not viscous. Alumina especially is a strong agent towards producing viscosity.

Prof. N. W. Lord defines the limits of slag composition by a very convenient diagram:

	Calcareous $6ROAl_2O_3$	
$2ROSiO_2$ Singulo Silicates Basic slags Stony, melt suddenly. Very liquid Oxygen ratio 1 : 1	Area of Fusible Slags.	$ROSiO_2$ Bi-silicates Acid Slags Vitreous, soften gradually Oxygen ratio 1 : 2
	$3ROAl_2O_3$ Aluminous.	

The oxygen ratio of $Al_2O_3 : SiO_2$ should lie between 1:3 and 1:2. This is equivalent to saying that the limits should lie between one molecule of alumina to 4.5 molecules of silica and one molecule of alumina to 3 molecules of silica. Expressed in ordinary relations by weight the limits are: 1 part of alumina : 2.64 parts of silica and 1 part of alumina : 1.76 parts of silica.

No complete table or curves showing the melting points of slags have as yet been prepared. R. Akerman* has determined the heats of fusion of singulo-silicate slags for a series of alumina-lime ratios:

Oxygen Ratio	0.20	0.25	0.30	0.40	0.50	0.70	0.90	1.00	1.20	1.50	2.00	2.35
Alumina Lime.												
Total heat of Fusion per unit Weight. Calories.	428	410	380	363	349	347	335	361	377	400	430	461

Gredt** gives the formation temperatures of singulo-silicates, $2ROSiO_2$, for a number of alumina-lime oxygen ratios:

**Stahl und Eisen*, 1890, p. 24.

***Jueptner's Siderology*, p 296.

Number.	Oxygen Ratio Alumina-Lime.	Temperature of Slag Formation.
1	0.00	1570°C
2	0.05	1526 "
3	0.11	1492 "
4	0.18	1468 "
5	0.25	1451 "
6	0.33	1439 "
7	0.43	1430 "
8	0.54	1422 "
9	0.67	1417 "
10	0.81	1412 "
11	1.00	1410 "
12	1.22	1430 "
13	1.50	1468 "
14	1.86	1526 "
15	2.33	1613 "

The curves on page 51 are taken from Jueptner's *Siderology* and illustrate the heats of fusion for various stages of acidity and lime-magnesia combinations.

In regard to the structure of slags we can distinguish glassy, stony and crystalline slags. Silicious slags, on rapid cooling, invariably change to the glassy condition, but any slag assumes the stony appearance if cooled sufficiently slowly. Highly basic slags are always stony and frequently show fine crystals in the interior especially if ferrous iron be present in larger amounts. Silicious slags show but slight tendency to crystallize. Highly basic slags or such low in alumina on exposure to air gradually fall to a powder due to the action of carbonic acid and water. On examining strongly basic slags with the microscope Dr. Passow* found crystals very much analogous to the crystals found in Portland cement, known as alite. Certain slags possessing a peculiar tendency to fall to powder due to an inter-molecular change similar to the dusting of Portland cement were found to contain a definite mineral showing double refraction and pronounced parallel striation. Dusting Portland cement clinker was found to contain the same crystals, known as felite.

J. H. L. Vogt, of Christiania, has made the most thorough and searching examination of the crystalline structure of slags. He has succeeded in identifying a considerable number of minerals in various slags by cooling them very slowly. In the table on page 52 a number of these minerals are enumerated and their composition given together with the type of slag in which they were found:§

**Stahl und Eisen*, 1903, Aug. 1st.

§*Jueptner's Siderology*, p. 208.

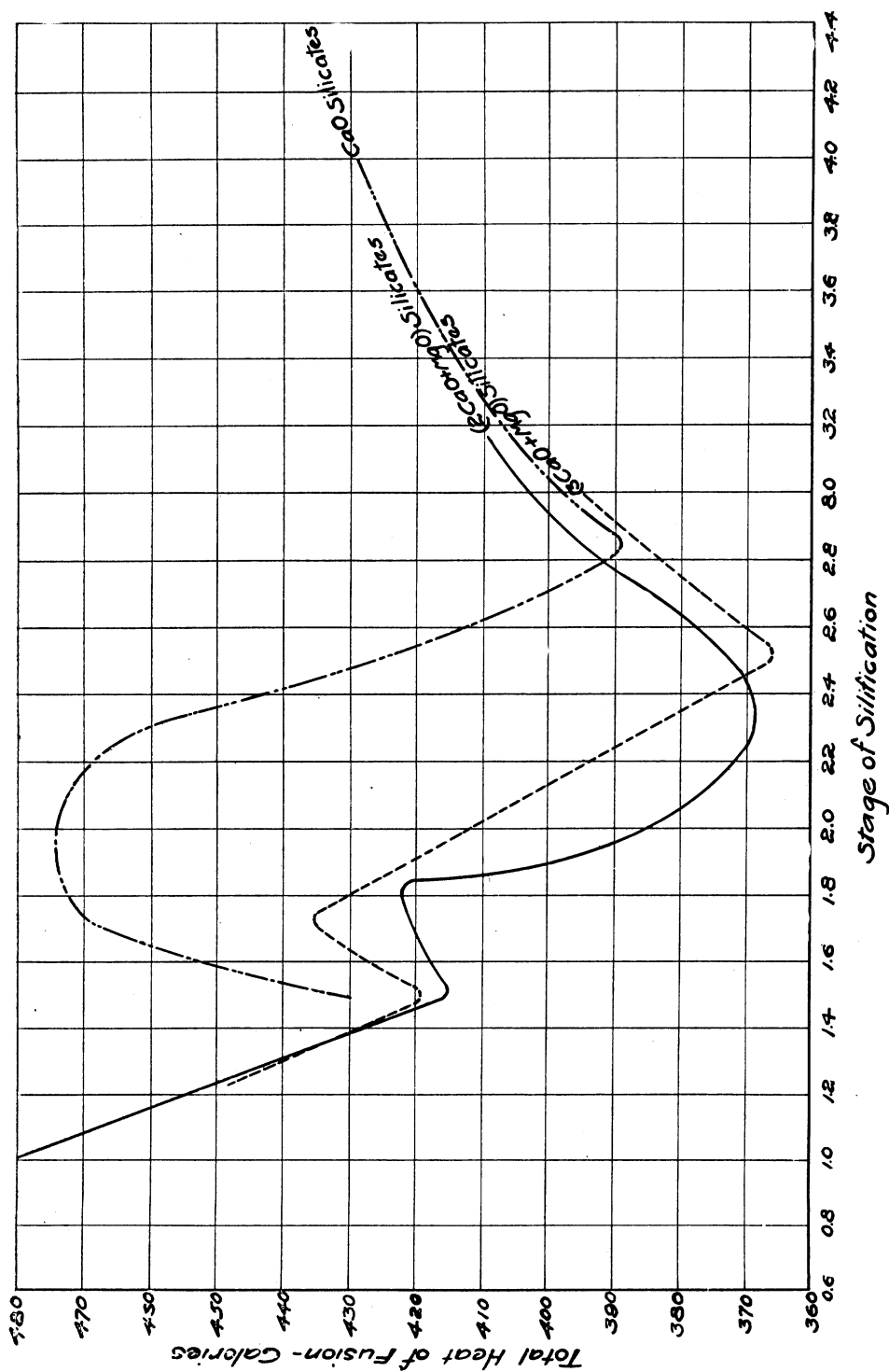


Fig. 3. Curves representing the heats of fusion of lime and lime-magnesia silicates of various acidities.

Oxygen Ratio of Slag SiO_2 RO	Typical Formula of Slag.	Minerals.
0.67	$\text{R}_3\text{SiO}_5 \dots$	Gehlenite $(\text{RO})_3\text{Al}_2\text{O}_3(\text{SiO})_2$ Tetragonal.
1.00	$\text{R}_2\text{SiO}_4 \dots$	Melilite $(\text{RO})_{12}(\text{Al}_2\text{O}_3)_2(\text{SiO}_2)_9$ Tetragonal.
1.00	" ...	Olivine $(\text{MgO})_2\text{SiO}_2$ Rhombic.
1.00	" ...	Fayalite $(\text{FeO})_2\text{SiO}_2$ "
1.00	" ...	Tephroite $(\text{MnO})_2\text{SiO}_2$ "
1.00	"	Montecellite CaOMgOSiO_3 "
1.00	" ...	Willemite $(\text{ZnO})_2\text{SiO}_2$ "
1.50	$\text{R}_4\text{Si}_3\text{O}_{10} \dots$	New, non-aluminous, calcareous, tetragonal, mineral: akermanite, $\text{R}_4\text{Si}_3\text{O}_{10}$
2.00	$\text{RSiO}_3 \dots$	Calcium Silicate, CaSiO_3 , hexagonal.
2.00	"	Wollastonite, CaSiO_3 , mono symmetrical.
2.00	"	Augite varieties $\text{CaO}(\text{Mg})\text{SiO}_3$, mono symmetrical.
2.00	"	Babingtonite $n(\text{Mn},\text{R})\text{SiO}_3 + \text{Fe}_2\text{Si}_3\text{O}_9$, Asymetrical.
2.00	"	Enstatite, MgSiO_3 , Rhombic.
2.00	"	Hypersthene } $\text{Fe}, \text{Mg}, \text{SiO}_3$, Rhombic.
2.00	"	Broncite }

In regard to the relation between the minerals and the composition of the slag, Vogt says: "A comparative examination of the analyses shows that the formation of minerals in the molten mass depends chiefly on the chemical composition of the average mass. The divergent physical conditions possible in the formation of the slags exert only a minimum secondary influence on the reaction provided a certain minimum time limit be not exceeded for the period of crystallization."

Calcined Clay.—Whenever dehydrated clay is required for pozzuolane purposes, be it for a pozzuolane cement proper or for mixture with Portland cement, it is of course readily obtained by calcining the clay either in a vertical shaft kiln similar to a limekiln or in a rotary cylinder furnace.

RAW MATERIALS OF THE NATURAL CEMENT INDUSTRY.

By natural cement we mean those natural, intimate mixtures of calcium carbonate and clay which when burnt to a temperature of approximately 900 to 1000° C. produce a hydraulic cement. The United States are rich in materials of this kind, and these cements have been an im-

portant factor in the development of our country during the greater part of the nineteenth century. They have been especially important during the canal-building period, during the construction of the American canal systems, the Erie canal of New York, the Pennsylvania and Ohio canals. In the construction of all these waterways hydraulic limestone was found at many places; large as well as smaller local deposits were thus discovered and used.

From what we now know of the nature of limestone we can realize without difficulty that these stones were apt to be of all sorts of compositions, high or low in clay substance. When they contain 75 to 80 per cent. of calcium carbonate and 25 to 20 per cent. of clay, they are called hydraulic limes, while those higher in clays come under the term Roman cement, containing 50 to 70 per cent. of calcium carbonate and 50 to 30 per cent. of clay. Both may contain varying amounts of magnesia. Physically, these materials may vary enormously, since they may be soft or hard, like clay in appearance, or compact as the densest varieties of stone. The harder, more rock-like hydraulic materials are preferred, since in manufacture it is desirable to work with larger lumps which are not friable, so that they may be stacked up in the kiln without impairing the draft and in order that the heat may pass through the mass uniformly.

We can, therefore, classify the natural hydraulic cements as follows:

- | | |
|---------------------------|---------------|
| 1. Hydraulic limes..... | { Calcareous. |
| | { Magnesian. |
| 2. Roman Cement Stone.... | { Calcareous. |
| | { Magnesian. |

The practical distinction between the hydraulic limes and the Roman cements is that the former after burning slake by themselves and evolve considerable heat, while the latter, though quite soft, must be ground to a powder and evolve less heat of hydration on slaking. In either class the magnesium carbonate may be anything from a trace to about four-fifths of the calcium carbonate, that is, for a content of 43.5 per cent. of calcium carbonate we may have 36.5 per cent. of magnesium carbonate, the sum of the carbonates being the maximum content of carbonates allowable in a hydraulic lime.

Owing to the fact that hydraulic lime is such an extremely irregular source of cement making material, it need not be considered in detail here, but we shall discuss only the Roman cements as representing the general type of natural cements.

In the following table some typical analyses of Roman cements are given:

Number.	Percentages.							Molecular Ratio RO:SiO ₂	Oxygen Ratio RO : Al ₂ O ₃ : SiO ₂
	Silica.	Alumina.	Ferrie Oxide.	Calcium Carbonate.	Magnesium Carbonate.	Potash.	Soda.		
1	15.65	6.80	2.50	69.00	3.40	.....	.....	2.72 : 1	2.72 : 0.76 : 2
2	16.41	5.44	3.38	46.52	26.40	.....	.....	2.85 : 1	2.85 : 0.58 : 2
3	32.06	21.27	2.11	35.56	7.00	.....	.....	0.82 : 1	0.82 : 1.17 : 2
4	23.34	8.70	1.60	38.34	23.24	.....	.....	1.70 : 1	1.70 : 0.66 : 2
5	22.73	10.43		34.54	21.85	3.63		1.59 : 1	1.59 : 0.81* : 2
6	24.30	7.22	5.06	33.70	20.94	.....	.....	1.30 : 1	1.30 : 0.51 : 2
7	22.62	7.44	1.40	40.68	22.00	2.23		1.77 : 1	1.77 : 0.57 : 2
8	24.40	6.20		41.80	16.29	1.52		1.51 : 1	1.51 : 0.45* : 2
9	27.60	10.60	0.80	33.04	7.26	7.42		0.91 : 1	0.91 : 0.68 : 2
10	28.02	10.20	8.80	44.48	1.00	0.50		1.20 : 1	1.20 : 0.64 : 2
11	22.70	7.40		36.31	25.72	.....	.....	1.77 : 1	1.77 : 0.56* : 2
12	25.16	6.33	1.71	36.08	18.38	5.27		1.38 : 1	1.38 : 0.44 : 2
13	22.91	8.00	1.90	61.76	2.70	.....	.....	1.70 : 1	1.70 : 0.62 : 2
14	24.74	16.74	6.30	41.80	8.60	6.18		1.27 : 1	1.27 : 1.19 : 2

*The Al₂O₃ includes the Fe₂O₃, the latter not having been determined.

Analysis No. 1* represents a Roman cement mined at New Lisbon, Ohio, belonging to the Lower Freeport horizon, a hard rock which produces a most excellent cement when properly burnt.

No. 2* is a similar cement rock from Bellaire, Ohio, which is mined in the hills below this city.

No. 3* is a calcareous rock found at Barnesville, Belmont county, Ohio, lying between the Pittsburg and Meigs Creek coals, Nos. 5 and 9.

No. 4 is a hydraulic shale obtained near Defiance, Ohio, highly charged with bituminous matter and containing distinct layers of pyrites which, unless removed by hand picking, interfere seriously with the proper burning of the material. The quality of cement produced from it, however, is high and it has been used in a great many buildings of Auglaize county.

No. 5 represents the Rosendale cement rock, one of the typical American Roman cements. It is chiefly found in Ulster county, New York, and is a dark blue, hard rock brought to the surface by upheavals and is hence tilted in every conceivable inclination. It is obtained by mining.

No. 6 is an average analysis of several Rosendale Roman cements.

No. 7 represents the Akron cement, of the type of the Rosendale Roman cement and mined at Akron, New York.

No. 8* is an analysis of another well-known American Roman cement, being mined and burnt within a small area along the Ohio river extending about fifteen miles north of it near Louisville, Ky., being known on the market as Louisville cement.

*Ohio Geological Survey, Vol. VI, Chapter on Cements, by Prof. N. W. Lord, p. 673.

No. 9 shows the analysis of the Utica cement, mined at Utica, Ills., the rock being a clayey limestone of Lower Silurian age.

No. 10 is a natural cement found at Round Top, Md.

No. 11 is a Roman cement manufactured near Buffalo, N. Y., of the Rosendale type.

No. 12 also is a cement of the Rosendale type, but manufactured at Milwaukee, Wis.

No. 13 represents the famous Lehigh Valley rock, mined near Allentown, Penn., in the villages of Copley, Siegfried and other places. The Roman cement made from this rock is of high quality and is also being used in the manufacture of Portland cement, limestone lower in clay being added to produce the correct composition.

No. 14 is a cement rock obtained at Cumberland, Md.

On examining the chemical composition of these hydraulic cements it is found that the average molecular ratio of $\text{RO}:\text{SiO}_2$ is 1.60:1 and that the average oxygen ratio, $\text{RO}:\text{Al}_2\text{O}_3:\text{SiO}_2$ is 1.60:0.69:2. The variations in composition, it will be noted, are very great indeed, and it seems as if the hydraulic activity were not a function of definite compounds, but is dependent on a pozzuolanic reaction which merely requires enough base to "unlock" the silica. The difference in the rate of setting of these cements is evidently governed by their content of alumina as well as of calcium oxide. Beside the chemical composition the uniformity of composition of a rock deposit, its fineness of grain and intimacy of mixture of the carbonates and the clay must be carefully considered. Coarse, crystalline limestone with irregular patches of clay would not be suitable at all, the same being true of fine grained carbonates and coarse clayey matter. On dissolving a sample of cement rock in hydrochloric acid, filtering off the residue, treating it repeatedly with hot sodium carbonate solution and finally washing out the reagents used, the residue of clayey matter can be examined. The photograph on page 56 shows the residue thus obtained from Rosendale cement, as seen under the lower power of a microscope. It was found to consist of amorphous clay substance, shown by the dull non-crystalline patches, more or less crystalline orthoclase fragments clouded around the edges by kaolinization, some flakes of mica and sharp edged crystalline fragments of quartz.

RAW MATERIALS OF THE PORTLAND CEMENT INDUSTRY.

The constituents introducing calcium oxide may be limestone, marl, slag, or industrial waste products. The clay components may be introduced as clay or mixtures of clay and sand, or as cement stone, a calcareous material high in clay base. In the great majority of Portland cement plants the mixture consists of two distinct components, the one introducing the clay, the other the necessary lime. The cement stones of the Lehigh Valley, containing more than the required clay, need the addition of a

purier limestone. So also with blast furnace slags, which are often a most excellent material for cement manufacture. Both the natural cement rock and the slags have been discussed in previous paragraphs and there remains now the discussion of the clays and calcareous material with special reference to the Ohio resources.

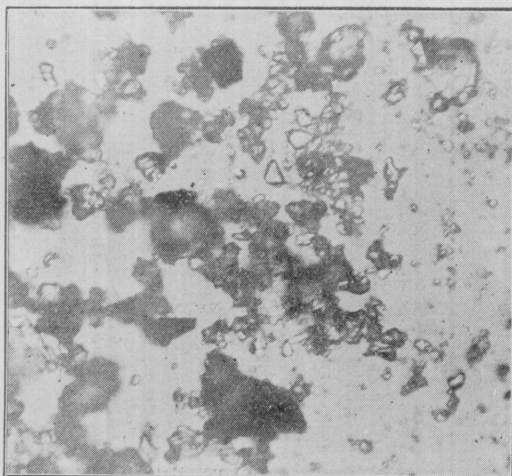


Fig. 4. Clay residue of Rosendale cement, seen under the microscope.

THE CLAYS.

Clay may be defined as a complex derivative rock, generally of a soft and earthy nature, in which a mass of mineral debris of variable composition and amount is bonded and held together by a matrix of kaolinite, or allied hydrous silicates of alumina. The distinguishing characteristics of clays as a class are, first, plasticity when mixed with the right quantity of water, and second, the property of hardening by heat, to form strong and durable silicates not easily destroyed by weather or other natural agencies. This definition is not rigidly exact, as some clays are not plastic, and others do not harden to make durable silicates by heat, but these are minor exceptions to the group as a whole.

In order to fully comprehend the nature of clay and to understand the source of its advantages and disabilities as an ingredient in cement mixtures, it is necessary to devote some space to a discussion of its origin and classification.

Origin of Clay. —As before stated, clay is a complex rock and not a single mineral. The characteristic or essential part of it, however, is the mineral kaolinite, which is derived from the weathering of feldspar and many other igneous aluminous silicate minerals.

Considering the typical feldspar, orthoclase, we find that it possesses the formula: K_2O , Al_2O_3 , $6SiO_2$ and the following percentage composition:

Silica	64.68 per cent
Alumina	18.43 per cent
Potash	16.89 per cent

being an alkali-alumina silicate.

Kaolin, on the other hand, has the formula Al_2O_3 , 2SiO_2 , $2\text{H}_2\text{O}$ and the percentage composition:

Silica	46.3 per cent
Alumina	39.8 per cent
Water	13.9 per cent

which is a hydrous aluminum silicate.

The significant changes noticed are the removal of the potash and a part of the silica and the introduction of chemical water. The obvious physical change is in the metamorphosis from a hard, crystallized substance to a material soft and plastic in character.

While the feldspar has undergone decomposition, the augite perhaps has also been attacked in a similar manner, while the mica is much slower to succumb to the destructive agencies and the quartz remains practically unchanged as far as chemical atmospheric influences go. It can be readily seen that thus the end product of the decomposition of the granite is not, in the nature of the case, a homogeneous product, but must consist of kaolinite clay substance, mixed with undecomposed fragments of feldspar, weathered and unweathered augite, mica and quartz. The material resulting from the decomposition of the augite closely resembles clay substance, but instead of being white in color it is discolored by the iron from the original mineral, resulting in a red clayey mass.

Since, however, the number and variety of aluminum silicates which on decomposition result in some modification of the clay substance is very large, it is evident that the end product must be extremely variable in composition, resulting in hydrous aluminum silicates of varying chemical and physical character, all of them being contaminated with quartz. For instance, in speaking of feldspar, the term includes both the acid feldspars, like orthoclase, albite, and oligoclase, and the basic ones, like labradorite and anorthite; the iron carrying minerals may be augite, mica, hornblende, or even magnetite, limonite and pyrites.

The character of the clay must invariably be dependent on the character of the rock from which it is derived, and since there are so many kinds of igneous rocks, granite, syenite, dolerite, trachyte, gabbro, diabase, andesite, porphyry, we see again how heterogeneous a product the primary clay materials must be. White clays are, hence, exceptional, owing to the great abundance of iron carrying minerals, and are found only under favorable circumstances and hence are comparatively valuable.

The clays so far discussed are primary clays, produced by decomposition from the original rock *in situ* without transportation of the decomposed material. Since water, that all-powerful

agent, shows its influence everywhere, especially with reference to the transportation of materials, there are comparatively few localities that escape its action. The natural result, hence, must be that the decomposed material is carried away, ground up in creeks and rivers and deposited, the coarse in rapidly moving water, the finer in still water, and the finest is carried out into the ocean or lakes to form the great deposits of shales. In this great grinding and deposition process the various portions of rock debris are mixed more or less thoroughly and can be said to possess a certain homogeneity only when deposited in deep still water, producing our fine-grained shales. All clays deposited by water are called secondary clays and comprise the vast areas of clay which we know in geology, the primary clays being more accidental in nature and small in extent. Thus the eternal cycle goes on. The igneous rocks are decomposed, worn away, carried by the streams and deposited; the beds of shale, built up slowly in this manner by movements of the earth's crust, are exposed and are again worn away to be redeposited.

The clays of this class differ from the primary clays in several respects. Owing to the fact that they have undergone transportation and mechanical abrasion they are bound to be finer grained than the first class of clays and hence plasticity, the characteristic property of clays, is much more fully developed, except, of course, when sand or similar non-plastic material is mixed with it on the way from the old rock to the place of sedimentation. The work done by the water upon the mixture of rock minerals may be placed into four functions:

1. Transportation.
2. Grinding.
3. Mixing.
4. Grading by sedimentation.

Transportation must, of course, take place if the primary rock is to be converted into a sedimentary one. The agent of transportation is always water, gathering in the mountains from small and weak streams fed by glaciers or springs. As these grow in volume and rush down into the valleys they carry with them large pieces of rock which are left behind at the foot of the mountains owing to the decrease in the velocity of the stream. With the slower current smaller particles of rock are brought along till finally near the sea the solids carried by the rivers consist of the finest particles of mud. We see thus that the size of the rock fragments transported by the water is a function of the current velocity. According to W.Hopkins,* the transporting power of water increases as the sixth power of the current velocity; thus if the velocity is doubled its motive power is increased 64 times.

But as the rocks are carried along and rubbed against the stream bottom they are continually undergoing mechanical abrasion and the

**Physical Geology*, A. J. Jukes-Browne, p. 128.

amount of the finer particles is constantly increasing, which then are carried further down the stream till they either settle to the bottom, owing to the decreased stream velocity which cannot carry them any further or if fine enough till they have reached the still water of great lakes or oceans.

It is evident, of course, that all this grinding must bring about a thorough mixing of the rock products. If the mountain creeks brought down, for instance, the fine white kaolin resulting from the decomposition of feldspar together with ferruginous minerals it is evident that the clay substance is bound to be contaminated with the iron bearing materials. We can say, therefore, that sedimentary clays are always less pure than the white clay substance arising from the original rocks under favorable conditions. The purest sedimentary clay on being burnt shows invariably a more yellow or reddish tinge than the washed primary kaolin owing to the presence of more iron. But this, though of great importance to the potter, is not of any interest to the cement manufacturer.

Since, as we have seen, the rock particles are carried along by a stream until the current velocity becomes too small when they settle to the bottom, we can also say that the greater the velocity of the current the larger will be the size of the particles deposited by it. The more rapid the flow of the river the coarser will be the sediment on its bottom. Very fine clay materials will hence be deposited only in oceans or lakes where the water is still. But since the velocity of a river varies we find that sometimes coarse materials alternate with fine; even at the same point in a river coarser material may be deposited in the middle of the stream while in a bend or pool, the water being comparatively quiet, fine clay settles out. We cannot, therefore, expect to find uniform deposits of clay formed by smaller rivers and creeks, but must look for them in beds of large rivers, lakes and oceans.

Water deposition not only grades materials according to their size, but also according to their specific gravity. This is due, of course, to the fact that heavy particles settle first, followed by the other materials in proportion to their specific gravity. Similar particles of the same kind will hence be deposited together in horizontal layers. We must keep in mind this grading process of nature in order to understand why shales deposited in still water are so uniform in character, or why alluvial clays have such a varying composition.

Alterative Influences to Which Clays are Subject.—We can readily see how clays may be deposited under various conditions. If the stream has carried along clay together with very fine ground quartz the resulting deposit will be a silicious clay, if with ground calcite or limestone we shall have a calcareous clay, or if with organic matter bitumin-

ous or graphitic material. But even after decomposition the clays are subject to various changes, due to the chemical and physical conditions to which they may be exposed and geological disturbances which may arise. These changes are often very complicated, acting upon the clays simultaneously and reacting also upon each other. But in order that we may have a proper conception of the changes possible, we must consider each of the various influences and study the effect wrought by it upon the clays. It is evident, of course, that each of these actions has a different effect on different clays.

The influence to which clays may be subjected may be grouped together as follows:

1. Wearing away and redeposition.
2. Metamorphism due to $\left\{ \begin{array}{l} \text{heat,} \\ \text{pressure,} \\ \text{steam and other gases.} \end{array} \right.$
3. Chemical action.
4. Solution and crystallization.
5. Infiltration.
6. Leaching.
7. Concretionary action.
8. Glacial action.

Wearing Away and Redeposition.—No material is able to withstand the attacks of the great weathering agents, water and air, assisted by the physical factors, heat and cold, and durability is hence only a relative term of no significance geologically. As soon as a clay is deposited it is again subject to changes, more or less radical. It is worn away and transported by water, either to be redeposited as clay or to become part of another rock. If the clay happens to be pure it is liable to be rendered impure by this process, if already impure it stands some chance of being purified by the removal of coarse constituents, sand, organic matter, concretions, etc. Such is the case with certain glacial clays where a heterogeneous jumble of materials is worn away and redeposited free from all coarse mineral matter. This is the case in certain localities of northern Ohio, as at Milbury, where a glacial clay was by this process redeposited as a fine grained material in a fresh water lake and was thus freed from the rock debris peculiar to boulder clays.

Metamorphism.—In the mountain-forming periods of the earth's crust, when the rock strata underwent crushing and crumbling, both heat and pressure were brought to bear upon the rocks, changing their structure and character. Similar metamorphosis is experienced by the strata when coming in contact with fused masses of lava, where heat brings about the alteration. In this manner shale is readily transformed

into slate or the clays may even be brought to the condition of an igneous rock as soon as the heat is sufficient to melt them.

Steam especially in the superheated condition is a powerful agent in the decomposition of all silicates. This may readily be shown experimentally, when it will be found that even very acid silicates are decomposed without trouble. When in Germany extensive attempts were made by Professor Meyer to burn lime at a lower temperature by means of superheated steam so as to produce a better product for the purposes of the sugar industry these were eminently successful as far as the lime burning was concerned, but had to be given up because the kiln linings of fire brick and the iron pipes were destroyed so rapidly. We can readily see that clays in contact with superheated steam will be completely decomposed and their entire character destroyed. Similarly, the action of volcanic gases like carbon dioxide, hydrogen sulphide, etc., is bound to result in a material alteration.

Chemical Action.—The chemical changes which clays undergo represent a continuous chain of reactions which never cease. Though the chemical processes constantly taking place are infinitely numerous, we may distinguish principally two kinds of reactions, namely, oxidation and reduction. It is evident that these reactions involve principally those compounds which are easily oxidized and reduced, especially the oxides of iron and manganese, though the latter is present in clays in such small quantities that it may be neglected. If a clay happens to contain its iron in the state of the lower oxide, as the carbonate, or as the sulphide, FeS_2 (iron pyrites) the atmospheric oxygen brought in by water percolating through the deposit will convert it to ferric oxide or its equivalent, ferric hydroxide, or the sulphate. The whole character of the clay is thus changed, which is usually shown by the difference in color. A bank of shale, for instance, near the surface will possess a reddish or yellow color owing to the presence of the higher oxide of iron, while on working into it the color is found to be blue or gray, indicating ferrous iron. At the same time the surface shale will be found to be soft and easily worked while that in the hill is hard and rock-like.

Conversely, if an oxidized clay is exposed to reducing conditions resulting from organic matter the iron is changed to the ferrous condition, producing ferrous oxide and ferrous carbonate from the ferric oxide and ferrous sulphide from the sulphate. Hydrogen sulphide would naturally convert the iron to the sulphide.

There are a great many other possible reactions, such as the decomposition of ferrous or ferric sulphate and calcium carbonate resulting in the production of the ferrous or ferric hydroxide or oxide and calcium sulphate, carbon dioxide being evolved. Similarly, magnesium sulphate may be produced from the iron sulphides and sulphates as we know it to

enter the water from coal mines. Even free sulphuric acid may be produced under favorable conditions. Hydrous silicic acid brought into a clay may be precipitated by calcium carbonate and iron compounds by the action of organic acids.

All these reactions are coincident with the processes of solution, infiltration and crystallization.

If the tendency of the chemical reaction is to make the basic constituents of a clay more soluble they are taken up by water, dissolved and carried somewhere else and allowed to crystallize there. A clay may thus become purified while at the same time another material is being charged with the elements removed.

Solution and Recrystallization.—The matter of solution and crystallization has already been touched upon. Practical examples of this kind of action are quite frequent. In a shale, high in sulphur compounds, these become oxidized and soluble in water and are removed by the water to a lower point where crystallization takes place. If from the ferrous sulphate calcium sulphate is produced the latter will crystallize out as gypsum. The gypsum crystals thus produced may be frequently found in the soft clay at the outcrop of a shale deposit. Crystallization is not restricted to this one kind of substance, but may involve all of the soluble constituents and even may be observed in the clay itself where frequently the outlines of large crystals may be traced.

The crystallization of soluble constituents in a clay often condemn it for building purposes since these salts give rise to the unsightly efflorescence called "white wash" in the wall.

Infiltration.—We have already seen how soluble constituents may be dissolved and taken away to another part of a clay bed. These soluble constituents may, of course, come also from another rock and may be precipitated in the clay. Thus, soluble silicic acid brought in by deep seated springs is readily precipitated in the clay by calcium carbonate, iron salts by various organic compounds. As a result we would find veins or streaks of the materials introduced by infiltration wherever the water flowed, as we frequently find clays showing iron stain in an irregular network.

Leaching.—Wherever an impure but uniform deposit of clay is subjected to the action of organic acids and at the same time an outlet for the materials dissolved is provided it is bound to be purified by this leaching action. All of the soluble and also ordinarily insoluble compounds are made soluble and removed by the organic compounds. In time there will be left nothing but a mass closely resembling pure clay substance and whatever quartz was originally contained in the clay. Many of our Ohio fire clays have been produced in just this manner.

Concretionary Action.—Concretionary action is often active in collecting materials like ferrous carbonate or calcium carbonate in the clay and

causing it to form balls or pebbles of various sizes. Such concretions are met frequently and of course cause the clays to be irregular in composition. If they occur in too great a quantity they may render the clay worthless. Often, however, they may be removed by hand picking.

Glaciation.—By glacial action we mean in general the effect wrought upon rock material by the movement of ice upon it and the admixture with the rock debris brought along by the ice. This action may, of course, be more or less pronounced. It may remove the original clay, entirely, replacing it by the glacial drift material, as we know it to have taken place in large areas of Ohio where for instance the black shale has disappeared entirely, or it may produce a heterogenous mass of clay containing boulders of igneous rock and fragments from both igneous and sedimentary rocks. In any case extreme irregularity of composition will be produced and what might originally have been a good clay is now utterly unfit for the purposes of the cement industry. Unless such clays are worn away and redeposited there is little encouragement for their practical utilization.

Composition of Clays.—We have thus seen that in adding clay to a Portland cement mixture, we are adding a complex mixture of minerals, each of which has its own characteristic behavior in the vitrification process to which the cement is subjected. While no two clays are ever exactly alike, and while the fluctuations in composition and properties of clays may be very wide, it is still possible to make some general statements concerning them. They are known to be composed chiefly of four kinds of mineral matter. These elementary minerals, of which three are silicates and the fourth is wholly silica, are

Kaolinite or clay substance.

Feldspar and the feldspathic minerals.

Mica and the micaceous minerals.

Quartz or crystallized silicas.

These, blended in every conceivable proportion, form the predominating part of clays; in addition, there are frequently considerable quantities of ferruginous, calcareous, or carbonaceous matter, which may be in quantity sufficient to dominate and give character to the rock as a whole. Small quantities of other minerals are always present, but these are not factors of importance in the cement industry.

The behavior of a clay in a Portland cement mixture will, therefore, be the resultant of the behavior of its component minerals, which will now be studied.

Behavior of Kaolinite.—The importance of the clay substance in cement-making becomes manifest when we study its behavior with calcium carbonate or limestone on heating, and compare it with ground quartz. While fine quartz, ground in a ball-mill, on being heated with pure, fine cal-

cium carbonate only had 71.17 per cent. of silica rendered soluble in hydrochloric acid and sodium carbonate solution, clay substance in the shape of washed kaolin, on being treated exactly like the quartz, was practically all taken into solution. Again, if we heat kaolin and calcium carbonate together we find that the reaction between these two substances takes place at a much lower temperature than between very fine quartz dust or even silica prepared by precipitation from a sodium silicate solution. The expulsion of the combined water from the clay substance is soon followed by, or to some extent is even coincident with, the evolution of carbon dioxide from the calcium carbonate, so that at about 900° C. the clay substance, having lost the chemical water, has the latter replaced by calcium oxide, and in place of $\text{Al}_2\text{O}_3, 2\text{SiO}_2, 2\text{H}_2\text{O}$ we have $\text{Al}_2\text{O}_3, 2(\text{CaOSiO}_2)$.

Prof. Lunge and Dr. Schochor, two German investigators, showed ten years ago how much more available the combined silica of the clay substance is than even the amorphous silica obtained by precipitation.

Practical experience in cement making demonstrates clearly that the more "clay" a material contains, the more readily does it vitrify a cement mixture, that is, the lower a temperature is required.

It seems thus that combined silica in the shape of clay substance is the most efficient source of silica for the production of the lime silicates required in cement-making, viewing the subject from the chemical standpoint.

If pure kaolin were used for a cement mixture, there would be introduced, of course, a certain amount of alumina; for every part of silica we would have 0.86 part of alumina, the ratio of silica to alumina being $46.3:39.8=1.16$ to 1.00. Without going further at present, let it suffice to say that this brings in too much alumina and hence the problem of introducing readily available silica for the union with the lime cannot be solved by the simple expedient of using a pure clay, high in clay substance. Though as much silica as possible should be brought in as combined silica, the alumina content must be kept within the bounds prescribed by experience, and the balance of the silica must be introduced as free silica or quartz. It should be as fine as possible, so that nature's grinding process is utilized, saving the expense of artificial grinding. In some text-books, it is prescribed that a clay for cement-making should contain no free silica and that its alumina content should be about one-fourth of the silica content. This evidently is an absurdity, as for every part of silica the clay substance contains 0.86 part of alumina.

Feldspar.—The second constituent almost invariably present in clays is feldspar, in the shape of more or less decomposed fragments, still remaining from the incomplete decomposition of the original rock or brought in from other rocks by way of water transportation. The particles, according to the degree of grinding which they have undergone, are coarser or finer, like the particles of sand. As a rule they are finer than the

quartz, being less resistant to mechanical abrasion, but coarser than the clay substance. The term feldspar used in this connection is not strictly accurate, since there are a number of feldspathic minerals having various compositions. Yet since one kind of feldspar, the orthoclase, predominates so largely, the error for all practical purposes is not great enough to affect the technical results. In speaking of feldspathic matter we, therefore, mean orthoclase. In some clays, oligoclase is more abundant than the orthoclase, but anorthite is as a rule insignificant in amount.

The following table of chemical compositions will show the difference in the constitution of four feldspars:

Name.	Chemical Formula.	Percentage Composition.					Percentage Ratio of Silica to Alumina.
		Silica.	Alumina.	Potash.	Soda.	Calcium Oxide.	
Orthoclase.	$K_2O \text{ Al}_2O_3 \text{ 6SiO}_2$..	64.70	18.4	16.9	.....	.....	3.52 : 1
Albite.....	$Na_2O \text{ Al}_2O_3 \text{ 6SiO}_2$	68.70	19.5	.....	11.8	.....	3.55 : 1
Oligoclase..	$Na_2O \text{ CaO 4.5 SiO}_2$	63.00	24.0	.....	10.0	3.0	2.63 : 1
Anorthite..	$CaO \text{ Al}_2O_3 \text{ 2SiO}_2$..	43.20	36.7	.....	.....	20.1	1.18 : 1

The Function of Feldspar in Cement.—Feldspar, like kaolinite, is a silicate, it being a double silicate of alumina and alkali. The silica, being in the combined state, is readily available for the purposes of cement-making, and hence we find that on heating it easily combines with the lime. The difference between clay substance and feldspar in this respect is not great. Clay substance is more readily decomposed by lime on heating, but this is to some extent due to the extreme fineness of its particles and their shape, which makes them especially ready to come into intimate contact with the lime particles. Feldspar is hence an admirable source of silica. The alkali, being a powerful flux, causes the clay containing feldspar to become less refractory. While clay substance is an ideal refractory material, fusing at a temperature above the melting point of platinum, approximately at 1830°C ., feldspar melts at about 1290°C . Hence any content of feldspar in clay is bound to reduce the melting point of the latter unless it has already been lowered below the melting point of feldspar by means of other fluxes, like iron, lime, magnesia, free alkalies, etc.

We can therefore say that feldspar in clay which is used for making cement reduces the temperature of combination with lime, first on account of its initial greater fusibility; second, because of its readily available silica. We can say, hence, that it is a desirable constituent of clay, and the more so because it brings in a comparatively small amount of alumina, one part of silica introducing only 0.284 part of alumina.

Some writers object to the presence of the alkalies, potash and soda brought in by the feldspar, claiming that it does not lower the temperature of combination (or clinkering) and hence is useless; also that it causes the cement to set too rapidly, and again that the free alkalies resulting from the decomposition of the feldspar by the lime are liable to cause injurious efflorescence.

The writer in his experiments has found that these claims are exaggerated. The clinkering temperature was reduced by the addition of even small amounts of feldspar and the cements produced were of normal setting qualities.

Micaceous Minerals.—These are found in all clays, owing to the fact that mica is a mineral resisting atmospheric influences extremely well, due to its parallel cleavage. Since the shape of the particles as flakes causes them to float readily, we find them invariably associated with clay substance, from which they cannot be removed by any washing process. But as a rule the amount of micaceous minerals present is not great, though they are never absent.

The principal mica is muscovite, $K_2O_3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$, which we find has a strong similarity in composition to feldspar (orthoclase), since it contains only two more molecules of alumina than feldspar. We might say therefore that it is a somewhat weaker flux than orthoclase. In regard to the availability of the combined silica, of course, there can be no difference.

The fusibility of mica has been compared with that of feldspar, both being ground very finely and incorporated in a clay body.* It was found that 2.308 chemical equivalents of mica exert the same fluxing power as one equivalent of feldspar, other things being equal. This fluxing ratio is probably still lower for clays which have not undergone extremely fine grinding by the wet process, as the flakes of mica are very difficult to reduce to impalpable powder, and in the shape of flakes the mineral has no appreciable fluxing influence upon the clay mixture.

From the chemical standpoint we can safely say that for all practical purposes mica may be collected under the heading of feldspathic minerals, especially since the amount present is but small, so that really the only difference between a feldspathic and a micaceous clay would be a somewhat higher fusing point. By adopting this assumption the analytical work of separating the minerals of a clay is simplified considerably. As has already been said, the bulk of the mica is decomposed as readily by the action of the calcium oxide at higher temperatures as the feldspar, but the reaction is governed much more by the amount of grinding the mica has undergone, that is, by the size of the flakes, as the structure makes fine disintegration very difficult.

The Quartz in Clays.—The behavior of quartz in cement mixtures has been discussed partly in other connections. It is found in clays in grains

*R. T. Stull, "The Fluxing Power of Mica in Ceramic Bodies," Transactions American Ceramic Society, Vol. IV, page 225.

of all sizes and the particles may be worn by the natural grinding process more or less or not at all. Since we know that it should be as fine as possible so as to render it fit for the cement reaction without the expense of grinding, we should select such clays as have been ground fine by natural processes and have been washed out and redeposited in still water. Such clays are the shales and the glacial clays of the lake regions of New York, Indiana, Wisconsin and Ohio, as, for instance, the Albany slip clay of New York and the lacustral clay of Millbury and Bryan in Ohio. Geology thus aids us in finding and investigating suitable clay materials and determines whether a proper material can be furnished by a certain locality or not.

The Rational Analysis of Clays.—In speaking of clays in general we mean, according to what has been already said, natural mixtures of three mineral groups:

Clay substance.
Feldspathic minerals.
Quartz.

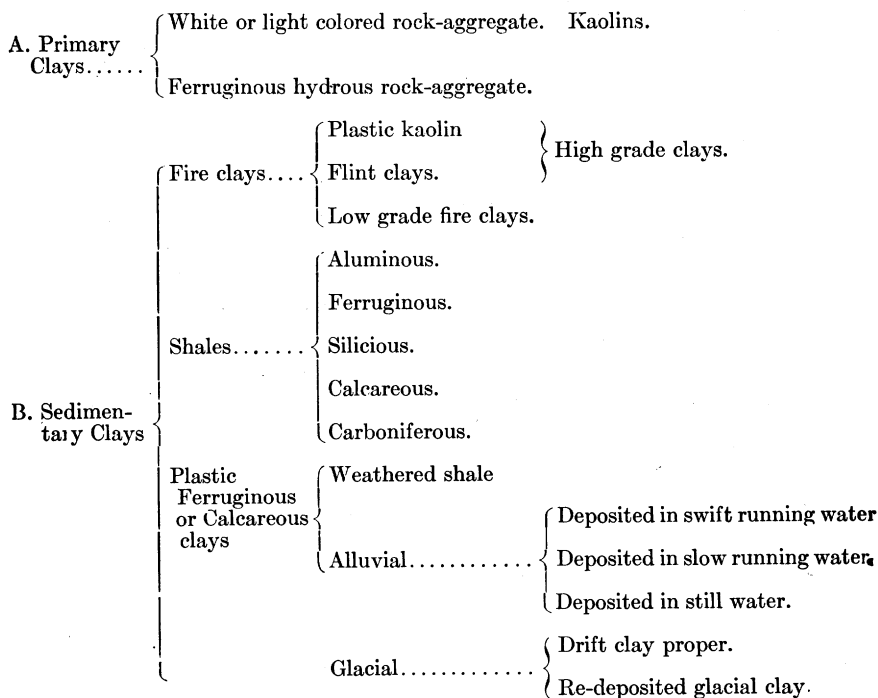
It must be, therefore, of interest to know just what proportion of a clay is clay substance and what free silica or feldspathic minerals. This is best determined by a chemical method, depending on the fact that clay substance is soluble in hot concentrated sulphuric acid and hot sodium carbonate solution, while both feldspar and quartz are not. By such a treatment all of the clay substance is removed, leaving only the quartz and feldspathic minerals. On analyzing this residue the amount of alumina and ferric oxide shows the percentage of feldspar present, since quartz can be assumed to consist of pure silica. Knowing the amount of the alumina and ferric oxide, the silica belonging to the feldspar is readily calculated, since the ratio between the R_2O_3 compounds in orthoclase feldspar and the silica is as 1:3.52, that is, for every per cent. of alumina plus ferric oxide, we have 3.52 times this amount of silica. The total amount of silica in the insoluble residue minus the calculated amount of silica belonging to the feldspar will give the amount of quartz and the total amount of feldspar is found by adding the silica (calculated) to the alumina and ferric oxide, the calcium and magnesium oxides and the alkalis all found in the insoluble residue. The details of this method will be given later under its proper heading.

Though this method of mineral analysis can lay no claim to scientific accuracy, it is of great practical value in giving a picture of the mineral structure of a clay which is of much greater direct benefit than the mere gross analysis.

Other Silicates.—Other natural silicates than those composing the clays have so far found no general application in the manufacture of Portland cement, but for certain purposes the use of certain silicious rocks low in iron is not an impossibility; for instance, for the manufacture of

white or very light-colored cement. Such rocks would be the pegmatites, similar to Cornish stone, used so extensively in the pottery industry; besides being low in iron, they are also low in alumina and high in silica, which would produce, if properly made, a safe cement, slow-setting, without the use of plaster. This question deserves more practical attention than it has yet received.

Classification of Clays.—It will not be found advisable to attempt a classification going into all the variations of clayey materials; for the purpose of the cement manufacture a less complicated system will suffice.



1. Light Colored Rock Aggregate.—When igneous rocks of the granitic type break down under the influence of the weathering agencies, the transition from the feldspathic minerals and other aluminum silicates to hydrous kaolinitic substances is not sudden, but gradual. On top of a decomposing layer of granite we would have the finest grained clayey material, while on approaching the mother rock the rock found would bear more and more the character of the granite. Fragments of the old rock would be found surrounded by the more or less completely hydrated material.

If conditions happen to be such that the clay (kaolin) is obtained solely from the feldspathic rocks without admixture of augitic minerals or hornblende, the resulting material will be composed of clay substance ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$), more or less decomposed grains and fragments of

feldspar and grains of quartz. For the purposes of the cement manufacturer neither the pure clay substance nor the quartz are of any direct value, as the one brings in too much alumina to be suitable for cement making, while the other is too hard to be ground profitably on a large scale. Hence if the primary rocks are to be considered at all they must either be high in feldspar or high in very fine quartz. The latter is not all probable, as the primary rocks have not gone through a natural grinding process, and hence only the first case deserves consideration.

Feldspathic white clays may be used in the manufacture of white Portland cements, furnishing as they do the silica in the combined state and since they also introduce a powerful flux in the shape of the alkalis. Rocks of this type may even be considered commercially if they should happen to contain a small amount of coarse quartz. If the feldspathic minerals are fine grained while the quartz is coarse, the latter can easily be removed by washing, as is done in the preparation of the kaolins for the market. If the difference in size between the particles of feldspar and those of quartz is not sufficiently great to separate them, since their specific gravities are very nearly alike, it would probably pay to grind these materials to the required fineness. This is due to the fact that white or very light colored cements sell at a much higher price, being especially suitable for decorative construction purposes. The white clay found at Mt. Holly, Pa., is an example of the kind of material under discussion.

2. Ferruginous Rock Aggregate.—If on the decomposition of the granitic rock the iron carrying minerals, like augite and hornblende, are in part or completely broken down and these hydrous aluminum silicates are mingled with those from the feldspar and perhaps magnetite is present also, the aggregate of these decomposition products may or may not be suitable for cement making purposes. Its suitability depends first on the softness of the decomposed minerals, the character and amount of quartz present, the content of iron, the amount of clay substance, the amount of undecomposed minerals and the uniformity of the clay bed. It is not often that a material of this character will be found satisfactory; in the majority of cases it would be too heterogeneous to be of any practical value for the purposes of the cement industry.

This statement applies to all primary deposits. Since no primary clays are found in Ohio a further discussion of them will be unnecessary.

3. Fire Clays.—This is a somewhat indefinite term, standing in general for clays which do not melt at high temperatures. A great deal of confusion prevails in regard to the conception of high temperatures among practical men. Though no definite limit has ever been put down, it may be said that no clay can be called a fire clay or refractory clay unless it stands a temperature approximately 3000° F. or 1650° C., expressed in the scale of fusible cones adopted by Seger as No. 26.

These clays may be white or yellowish in color when burnt; a clay burning almost a red color may be a fire clay, but the chances are against it. The value of a fire clay can, however, be determined definitely only by a refractory test.

The high fire-resisting quality of a clay is due, first, to the absence of fluxes which either were never present in the material or which have been leached out and removed, and, secondly, the fact that it corresponds more or less closely to the composition of the ideal clay substance, $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$, containing, as we know,

46.3 per cent. silica.
39.8 per cent. alumina,
13.9 per cent. chemically combined water.

The highest refractoriness is represented by a material of this composition, as many tests have shown. We can readily see, however, that any fluxes present will deteriorate the refractoriness. But it has also been proven by most extensive experiments that silica above that entering into the composition of clay substance will act similarly to a flux and reduce the refractoriness. A clay high in silica cannot, therefore, be a high-grade fire clay. On the market a fire clay is occasionally offered as being high in silica, a fact which the dealer supposes to be advantageous, but which really classifies the clay at once as of low grade.

This important law has been put to the test both theoretically and practically, but we must keep in mind distinctly that it applies only to clays already possessing a certain degree of refractoriness. Clays high in fluxes having a low fusibility intrinsically do not come under this law; clays of this kind are raised in the refractory scale by large additions of silica.

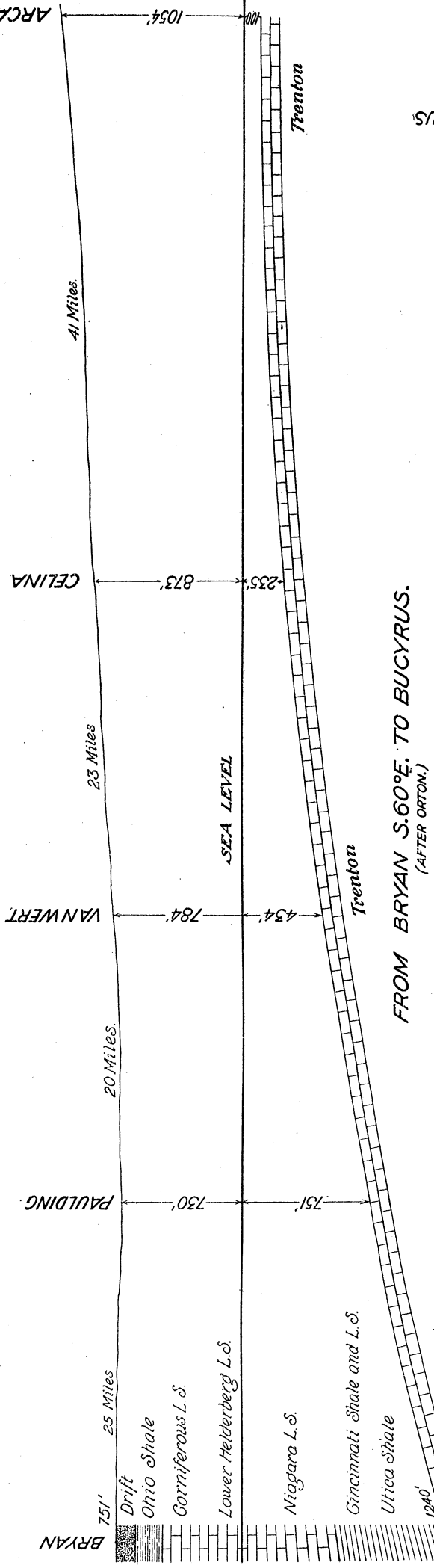
For cement making purposes the fire clays do not come into practical consideration excepting as furnishing the material for the kiln lining. This is due to the fact that, first, these clays are very high in alumina and consequently would produce dangerous quick setting cements unfit for use; secondly, the initial refractoriness of these materials is so high that it would increase the cost of manufacture unnecessarily. Though theoretically it is possible to manufacture a cement from limestone, fire clay and sandstone, practically it is not a feasible proposition. For this reason we shall not consider the highly refractory materials in detail.

In speaking of fire clays we must distinguish principally two kinds, the plastic and the hard, slightly plastic variety.

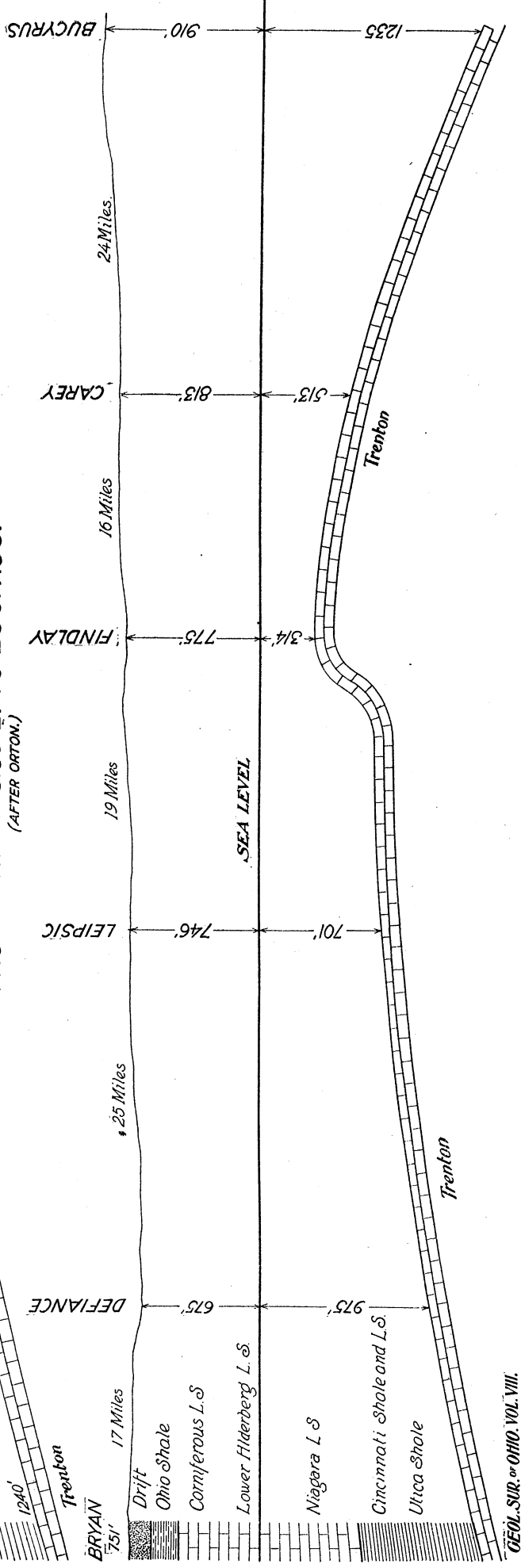
We have in Ohio no plastic fire clays of very high quality, but we have a number of them which are of sufficiently high grade to be used for good fire brick and other refractory wares. An example of this kind of clay is the Ballou fire clay from Muskingum county, which shows the following analysis:*

*Vol. VII, Part I, *Ohio Geological Survey*, p. 222.

SECTIONS SHOWING POSITION OF TRENTON LIMESTONE.
FROM BRYAN SOUTH TO ARCANUM.



FROM BRYAN S. 60° E. TO BUCYRUS.
(AFTER ORTON.)



	Per Cents.
Silica.....	59.43
Titanic acid.....	0.95
Alumina.....	26.76
Ferric Oxide.....	1.23
Lime.....	0.60
Magnesia.....	0.32
Potash.....	1.00
Soda.....	Trace.
Combined water.....	10.07

The hard fire clays, the so-called flint clays of Ohio, are of much greater purity than our plastic fire clays. They closely approach kaolin in composition.

The following analysis represents a typical Ohio flint clay, from Scioto County.*

	Per Cents.
Silica.....	44.60
Alumina.....	40.05
Ferric oxide.....	0.80
Lime.....	0.27
Potash.....	.....
Soda.....	.....
Chemical water.....	14.23

Physically flint clays are hard, conchoidal in fracture and when moistened with water show but slight plasticity. On being exposed to the atmosphere they break up into sharp fragments and after longer periods of storing the plasticity is increased, but the clay never becomes sufficiently plastic to be molded with ease.

Second Grade or Number 2 Fire Clays and Stoneware Clays.—

Beside the clay materials representing the highest grades of refractoriness we have a great number of clays in Ohio which are much less refractory, being higher in fluxes and free silica.

These clays associated with the coal measures of Ohio are the result of the leaching process already mentioned, by means of which the fluxing impurities have been removed more or less completely by organic agencies.

These clays are found in great variety of composition, as will be shown by the accompanying table of analyses. The main characteristics of the number two fire clays are, first, the ease with which they vitrify, which makes them particularly suitable for the manufacture of stoneware, though vitrification takes place very slowly and gradually; second, their fire resisting property, which corresponds approximately to the melting point of the Seger cone number 16, 1450° C., and third, the light buff color to which they burn. These clays are apt to contain concretionary iron sulphide in considerable quantities, which causes considerable difficulty and irregularity in the behavior of the materials on firing.

The following table† of analyses will show the chemical characteristics of these clays:

*Vol. VII, part I, *Ohio Geological Survey*, p. 220.

†Prof. Edward Orton, Jr., *Geology of Ohio*, Vol. VII, Part I. p. 94.

Number.	Per Cents of Ingredients.										Molecular Ratio	
	Silica.	Alumina.	Titanic Acid.	Ferric Oxide.	Lime.	Magnesesia.	Potash.	Soda.	Combined Water.	Moisture.	% Silica	% Alumina.
1	69.33	19.08	0.29	1.26	0.60	0.63	2.14	0.02	5.57	0.94	3.62	6.18 : 1
2	69.79	19.31	.....	.....	.....	.....	.....	.....	5.08	1.02	3.64	6.15 : 1
3	64.26	22.95	.....	1.28	0.45	0.37	1.81	0.15	6.74	2.05	2.80	4.76 : 1
4	65.20	23.05	0.55	0.99	0.58	0.58	1.45	.....	7.39	1.11	2.83	4.81 : 1
5	68.13	20.80	.....	1.20	0.42	0.37	2.28	0.27	5.72	1.00	3.27	5.56 : 1
6	56.44	26.60	.....	2.00	0.47	0.63	3.20	0.26	7.57	2.48	2.12	3.61 : 1
7	67.85	21.77	.....	1.06	trace	trace	1.93	1.11	6.67	.....	3.11	5.31 : 1
8	63.45	23.04	.....	2.03	0.72	1.03	0.53	0.93	7.81	SO ₃ 0.24	2.75	4.68 : 1
9	58.86	27.96	.....	1.40	0.51	0.64	2.75	.....	8.82	.....	2.10	3.58 : 1
10	62.81	21.41	1.26	2.65	0.58	0.85	2.89	0.21	6.52	1.47	2.93	5.00 : 1
11	70.00	19.35	.....	1.94	0.15	0.24	2.25	.....	8.35	.....	3.61	6.01 : 1
12	77.65	12.78	.....	3.32	0.55	0.45	1.30	.....	4.10	.....	6.07	10.36 : 1
13	71.58	18.31	.....	1.09	0.40	0.62	2.96	.....	5.95	.....	3.91	6.65 : 1
14	60.50	25.53	0.54	1.66	0.38	1.19	1.76	.....	7.98	.....	2.36	4.03 : 1

- | | | | |
|--------|---|---------|--|
| No. 1. | Brumage's stoneware clay, Roseville, Ohio. | No. 8. | No. 2 fired clay, Logan (analysis by L. E. Barringer.) |
| No. 2. | Walker's clay, Roseville. | No. 9. | No. 2 fired clay, Union Furnace. |
| No. 3. | Zanesville Stoneware Co. | No. 10. | Island Siding clay, Jefferson Co., No. 2 fireclay. |
| No. 4. | Uniontown stoneware clay. | No. 11. | Toronto sewer pipe clay, top. |
| No. 5. | Akron stoneware clay, average of several samples. | No. 12. | Elliottsville, No. 2 fireclay, used in making sewer pipe. |
| No. 6. | Salineville. | No. 13. | Typical stoneware clay (Langenbeck, Chemistry of Pottery, p.80.) |
| No. 7. | Canton stoneware clay. | No. 14. | Typical No. 2 fireclay, used in making yellow ware, same author. |

The mineral composition of typical Ohio clays of this character is represented by the following analyses:*

	Clay Substance.	Quartz.	Feldspathic Detritus.
No. 13.....	53.42	44.41	3.08
No. 14.....	76.05	19.54	4.28

The extreme limits of the contents of clay substance are about 40 to 80 per cent. It is interesting to note the compositions of the clay substance which are:

	Per Cents.	
	No. 13.	No. 14.
Silica.....	47.70	50.19
Alumina.....	33.47	32.87
Ferric oxide.....	1.96	1.84
Titanic acid.....		0.71
Lime.....	0.31	0.16
Magnesia.....	0.97	1.47
Alkalies.....	4.36	1.82
Combined water.....	11.13	10.50

Any of these usually very fine grained clays, with a percentage silica-alumina ratio of more than 3, can be made suitable for cement purposes by the addition of a little soft iron ore, say 1 to 2 per cent. The average percentage silica-alumina ratio is 3.22, while the average molecular silica-alumina ratio is 5.47. The latter ratios, being larger, are better for pointing out the differences. A molecular ratio of 5.1 might be accepted as suitable. But their use should be resorted to only when ferruginous clays sufficiently high in silica and sufficiently fine of grain are not available, owing to the fact that iron oxide lowers the vitrification point of cements considerably and hence stands for a lower fuel consumption. If, however, a manufacturer should be confronted by a choice between an irregular ferruginous clay deposit and a bed of silicious second grade fire clay, he would do much better to select the refractory clay, first, because it is apt to be much more uniform in composition and, second,

*Langenbeck, *Chemistry of Pottery*, pp. 67 and 80. Analyses by W. L. Evans, M. Sc.

because as a rule these clays are finer grained. Such a clay is the Roseville stoneware clay in which the percentage silica alumina ratio is 3.63:1. The magnesia in most of these clays is low and the only possible detrimental constituent to be considered would be the concretionary iron sulphide, which is injurious both on account of its irregular distribution and the sulphur it introduces.

Physically, these clays are rocky and hard when mined, but after being exposed to the weather for a short time they slake and crumble down. Their plasticity is developed only by grinding and working.

The principal geological horizons furnishing these clays are the Lower Mercer, Upper Mercer, Brookville and Lower and Middle Kittanning. Especially prominent is also the horizon of the Putnam Hill limestone.

Shales.—Geologically, we speak of shales as being, as a rule, fine grained clays, deposited in still water and later subjected to pressure, thus giving them the characteristic cleavage and structure. If this is carried further the shale becomes slate, and if another agent, heat, is introduced the metamorphism may be carried still further and the clay reverts to an igneous rock. The term shale thus stands as a guarantee, so to speak, of fineness of grain and also uniformity of composition, but does not specify the chemical composition. We may have shales high or low in refractory power, high or low in fluxes, though each is tolerably uniform within a reasonable area. We must hence keep in mind that the term shale stands for no specific chemical composition, but has only a geological meaning.

Aluminous Shales.—There is no reason why fire clays should not assume a shale structure. The most refractory clay known is a shale, the Rackonitz shale clay. Ohio has buff burning clays with shale structure which in composition correspond about to the number two fire clays, some of them being reported from near Logan. But what has been said concerning the fire clays applies also here and we may dismiss this class of clays as being too high in alumina.

Ferruginous Shales.—Shales high in ferric oxide are plentiful in Ohio and may give rise to a valuable source of cement material. The chief advantage of shales is, as we know, the great fineness of grain and uniformity of composition, but it has as its great practical disadvantage the fact that in the unaltered condition within the hills, it is hard and rather difficult to reduce to a powder, though shales may differ considerably in this respect, some being easier to reduce than others. But nature in many localities has solved this problem by causing the shale structure to become softened, giving rise to the so-called "rotten" shale which has all the good qualities of a shale, but not its hardness. Examples of this may be noticed along the outcrop of most shales, and on the surface of surface beds. The question whether such softened shale becomes available for manufacture must be determined by the amount of such material at hand. If a clay property covers a large area or if the

softened shale extends to some considerable depth, say 8 to 10 feet, the best policy will invariably be to work only the softened portion of shale along the surface, neglecting the hard main body of the shale entirely. Such a shale has usually a greenish or reddish color and is so soft that it can be readily cut with a knife, like soapstone. A material of this kind is to be greatly preferred to an alluvial deposit of clay liable to all the caprices of sedimentation by flowing water.

The color of unweathered ferruginous shale varies from dark gray and bluish gray, while the softened weathered shale assumes reddish and greenish shades.

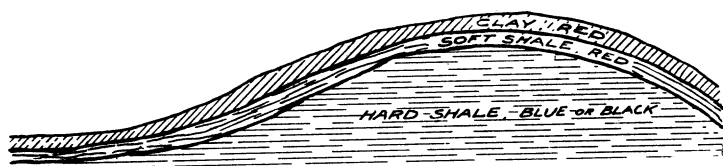


Fig. 5. Section showing the gradation of the hard shale in the interior of a hill to the soft layers on the surface.

On examining a hill of such shale (see figure 5) we find, first nearest to the surface a red clay containing fragments of shale followed by softened shale. The hard shale contains the iron usually as the ferrous carbonate and at the same time it may contain concretions, often to the size of a man's head, of ferrous carbonate, which of course are rejected. These "kidneys" of iron carbonate, if present in large quantities and in smaller lumps so that they cannot be removed by hand or machinery, cause the shale to become worthless for all manufacturing purposes. Another impurity liable to be found is iron sulphide (pyrites) in the hard shale which in the oxidized, softened shale becomes iron sulphate.

The ferrous carbonate of the hard shale becomes oxidized in the softened shale to the ferric oxide or hydroxide which gives to the shale its reddish appearance. Comparatively few shales contain iron solely as ferric oxide, one of the exceptions being the Bedford shale, a material much valued in the manufacture of front brick owing to the magnificent red color it assumes on burning.

As to the influence of the high content of iron in these shales on the cement to be produced, it may be said that as long as the content of iron does not run too high, say more than 10 per cent. of ferric oxide, the shales are to be preferred to clays lower in iron but higher in alumina, inasmuch as they cause the burning to take place at a much lower temperature and reduce the danger of spoiling the mixture in the burning by "dusting." The only possible objection which can be brought against a cement made from ferruginous shale is the darker color, which, of course, is due to the high iron content.

We may say, therefore, that ferruginous shales, provided they are sufficiently low in alumina and magnesia, do not contain too much concretionary iron and are not too hard, are well suited as cement materials. The limit of the ferric oxide content may be placed at 10 per cent.

In the consideration of these shales we must not overlook the fact that if they are too hard they are not the most suitable material, and in such a case one should try to find an area containing some of the weathered shale. The hard shale should be selected only if neither the clay produced from the shale by completed weathering nor the soft shale between the shale clay and the hard shale can be had.

The table* of analyses on page 77 will show the composition of some Ohio ferruginous shales which might become available.

A typical ferruginous shale when examined by the rational method of analysis gave the following mineral analysis:

	Per cents.
Clay substance.....	62.27
Quartz.....	25.53
Feldspathic detritus.....	12.07

Owing to the high content of iron these shales, of course, produce dark colored cements, but many of them are very suitable for cement making purposes as far as the chemical composition is concerned.

Silicious Shales.—We have in Ohio no large areas of distinctly silicious shales, but many local deposits are available. Often where a transition from shale to sandstone is found the shale as it approaches the stone becomes more and more silicious. If this silicious dilution is fine-grained, the material becomes extremely valuable for cement making purposes; in fact we might say that it would be the ideal of a cement clay. In reality, however, the sand addition is frequently too coarse grained and the resulting shale is not any better than any clay mixed with sand. The locating of a suitable silicious shale is therefore a matter of local conditions; for instance, we might find a high bank of shale of which only a part is silicious, a strata only a few feet in thickness.

Rather extensive deposits of silicious shales are found between the horizons of the Bedford and Cuyahoga shales. The Berea grit, a sandstone, frequently carries 8 to 10 per cent. of alumina and possesses the shale structure, making it a valuable material for cement manufacture. Though the Berea grit does not always show this structure, it invariably accompanies the Bedford shale, being found above the latter. The grit is usually very fine grained and when burnt assumes a red color. Judicious mixing and grinding together of the Berea grit and Bedford shale would in many cases produce a most suitable basis for the making of Portland cement. This seems to the writer to be a point well worth looking into

*Prof. Edward Orton, Jr., *Ohio Geological Survey*, Vol. VII, Part I, p. 132.

Number.	Percentages of Constituents.								% Silica % Alumina. Silica : Alumina.	Molecular Ratio Silica : Alumina.
	Silica.	Alumina.	Ferrie Oxide.	Lime.	Magnesia.	Potash.	Soda.	Combined Water.	Moisture.	
1	57.15	20.26	7.54	0.90	1.62	3.05	0.58	5.50	2.70	4.79 : 1
2	58.30	19.67	7.43	0.84	1.35	3.04	0.73	5.15	2.65	5.03 : 1
3	58.38	20.89	5.78	0.44	1.57	4.68	0.34	7.53	.....	4.74 : 1
4	57.28	21.13	8.52	5.79	2.13	.....	.....	5.22	.....	4.61 : 1
5	58.38	19.36	14.86	1.48	1.06	.....	.....	.....	.....	4.68 : 1
6	61.65	20.36	6.95	0.46	0.14	2.82	0.55	6.95	.....	5.15 : 1
7	52.19	14.61	10.00	.....	.....	.....	.....	5.62	12.62	6.05 : 1
Average	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.01 : 1

No. 1. Shale mined at Glouster, Ohio, horizon of Cambridge limestone.

No. 2. Same shale with addition of one-fourth leached drift clay.

No. 3. Shale mined at Darlington, Muskingum county, Ohio.

No. 4. Bedford shale, Northern Ohio.

No. 5. Shale from Canton, Ohio, Putnam Hill horizon

No. 6. Shale of same horizon, near Canton, Ohio.

No. 7. Shale from North Industry, Ohio, Lower Mercer horizon.

at places where limestone is also found near by. The Bedford shale extends from Lake Erie down to the Ohio river. Starting from Cleveland, Independence (Cuyahoga county), the shale extends south through Crawford, Delaware, Franklin, Fairfield counties, and is found to crop out in large sections at Waverly and Piketon.

Sections of this material in Franklin county run about as follows:

Berea grit.....	0 to 30 feet.
Chocolate Bedford shale.....	10 to 40 feet.
Green olive Bedford shale.....	0 to 20 feet.

Calcareous Shales.—Where shales are in contact with limestone or highly calcareous materials we are apt to find them rather high in calcium carbonate, which might run so high as to convert the shale into a hydraulic cement material, as is the case at Defiance, where the natural cement stone has a distinct shale structure. Larger areas of calcareous shale in Ohio are not known to the writer.

Carboniferous Shales.—These differ from the other shales in the fact that they contain carbonaceous matter varying from one or two up to 12 or 14 per cent. The most prominent shale of this type is the Huron shale, of Devonian age, lying on top of the great limestone beds. In color the shale varies from a black to a dirty green. The black shale is very hard, tough and almost non-plastic and resembles roofing slate. Where it has been exposed to the weather it appears as a yellowish clay, full of thin flakes of harder material. These pieces are often rusty brown on the surface and still black in the core. The lower green layers of the shale are much softer and contain much less, frequently almost no carbon.

A piece of the black shale thrown into the fire burns for a few minutes. Its carbonaceous matter consists principally of bitumen, which volatilizes readily and burns like a rich gas. The amount of this material is from 2 to 6 per cent.

The iron in this shale owing to the large amount of carbon present is, of course, all in the lower state of oxidation, being present as ferrous carbonate or ferrous sulphide.

This fact in connection with the large amount of organic matter makes this kind of shale exceedingly difficult to handle for the clay worker, though not interfering with cement making. While the bitumen is a great tribulation to the brick maker it would work beneficially to the cement manufacturer, inasmuch as the carbon would help burn the cement mixture, making a considerable saving in the fuel expense, provided, of course, that the chemical composition of the shale otherwise is satisfactory.

The following is an analysis* of the black Huron shale, sampled at Columbus:

*"Ohio Geological Survey," Vol. VII, Part I, p. 133.

	Per cents.
Silica.....	58.38
Alumina.....	20.89
Ferric oxide.....	5.78
Lime.....	0.44
Magnesia.....	1.57
Potash.....	4.78
Soda.....	0.34
Carbon.....	2.71
Chemical water, etc.....	4.82

In another sample of this shale there was found an iron content of 10.67 per cent. (as ferric oxide), of which 7.96 per cent. was ferrous iron, reported as ferrous oxide. The same shale was likewise found to contain 1.63 per cent. of sulphuric anhydride (SO_3) soluble in water.

From this the inference must be drawn that the material is liable to be too high in sulphur to be used as a satisfactory cement material. But that does not mean that this is true of all the shales; this point must be determined for every particular locality where this shale is found.

Plastic, Ferruginous Clays, Brick Clays, Weathered Shales.—As the shales succumb to the influence of the atmospheric agencies they gradually lose their shale structure and become again clays, with of course the same chemical composition, except that all oxidizable substances are converted into the higher oxygen compounds. Ferrous carbonate is decomposed and becomes ferric oxide, iron pyrites is changed to ferric sulphate. As a result we have in place of the hard mass showing a pronounced parallel structure a soft clay, possessing a much greater plasticity than did the shale. On the surface and outcrop of every shale deposit, we find, hence, plastic clay, and if the shale is suitable for cement-making by virtue of its chemical composition and fineness of grain the clay derived from it is much more valuable, since its softness renders it so easy and cheap to grind. In addition to this comes the uniformity of the composition, a property peculiar to shales, so that a shale clay is apt to be a material of magnificent working qualities.

Alluvial Clays.—As we have already seen, the clayey and sandy materials carried along by a stream are deposited according to their size and specific gravity dependent on the velocity. The swifter the stream flows the coarser will be the matter deposited by it. We call the comparatively fine rock matter deposited by a river alluvium.

Usually the rivers flow through a narrow plain within which the stream winds from side to side and over which the water spreads in times of flood. The larger the river the wider will be this plain. At the same time the river erodes for itself a deeper and deeper bed, so that extensive banks and terraces are formed on both sides of the stream.

The character of an alluvial clay is hence largely dependent upon whether the stream was flowing rapidly or slowly, whether it was a large or small, deep or shallow river, whether the course was straight or crooked. From this it follows that in looking for a suitable alluvial clay

for cement manufacture we ought to know something in regard to the old or present river drainage which produced it. If the old river bed indicates a narrow stream with a rapid fall it would be idle to expect to find in its valley a fine grained clay. In most cases the old river valley is outlined by the gravel beds or terraces (see figure 6), so that its

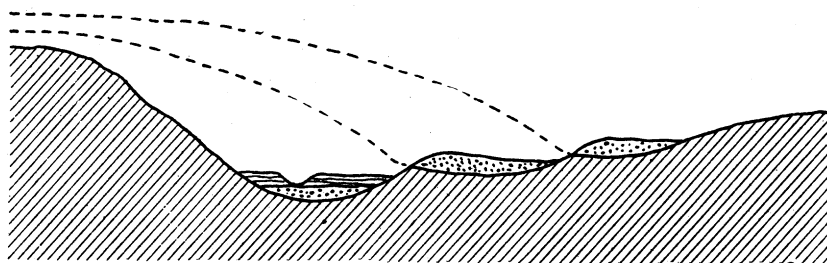


Fig. 6. River Terraces.

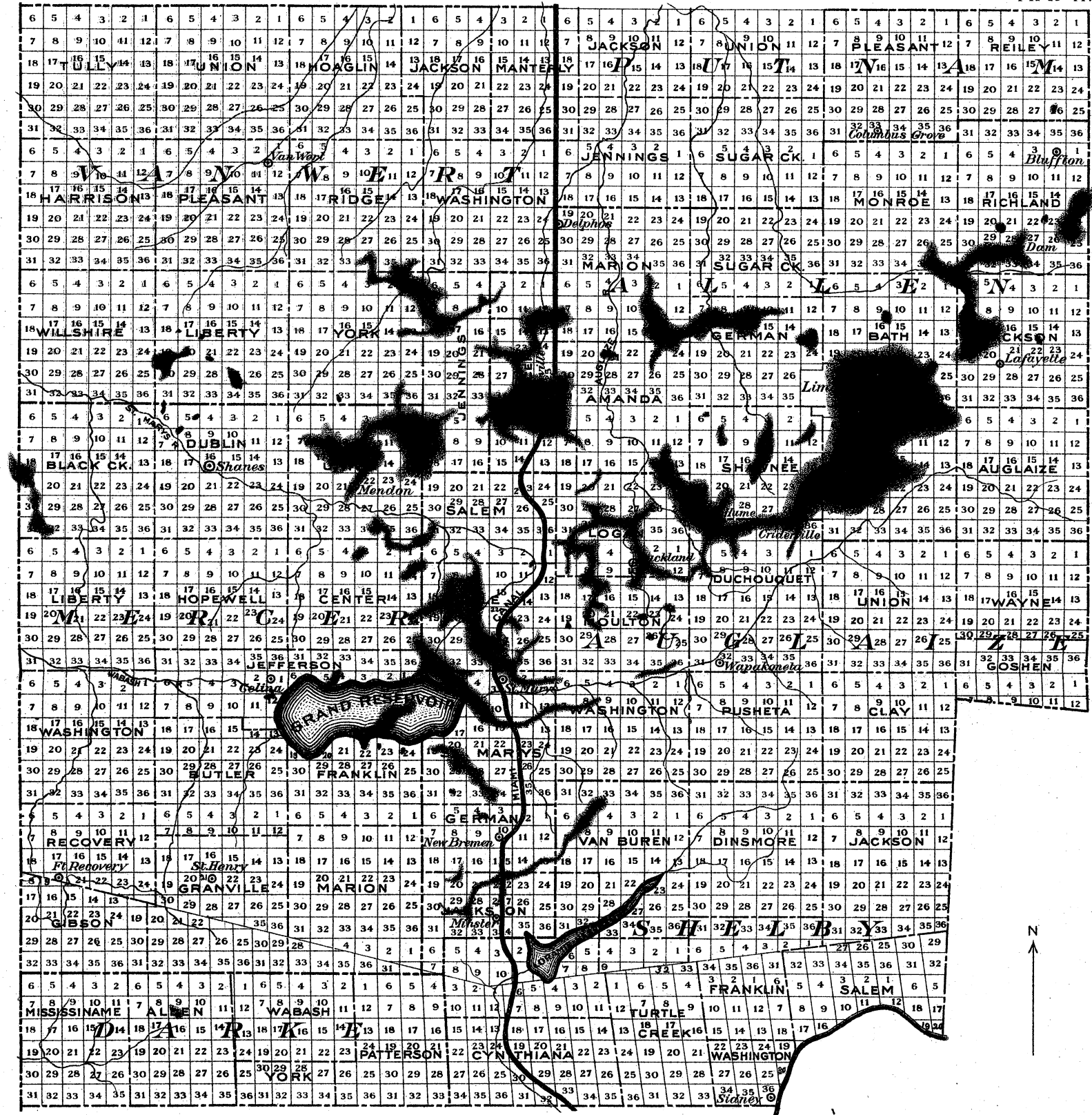
course can be followed with comparative certainty. If on the other hand the indications are that the stream was large and had a low velocity we have reason to expect that the fluctuation in the fineness of the clay material will be insignificant, and hence it is suitable as far as the physical characteristics are concerned. Again in a large river with somewhat greater velocity but with many curves and bends we should be encouraged to expect fine grained clay along the pools formed by the bends in which the water is in a state of comparative quietness and hence the particles deposited are very fine.

River deltas are a source of a great deal of the very finest material, since there the velocity of the current is smallest and the chance to deposit the load carried by the water is greatest.

It is important, therefore, that we should study and know the geological conditions under which the clays in question have been deposited. If found in an old river valley we should trace carefully all evidence in regard to the river now disappeared. If this were done much disappointment would be avoided. Frequently it has been found that a bed of very fine grained clay satisfactory in every respect degenerates at once into a coarse sandy clay or even gravel. It must be remembered that naturally the chemical composition will also vary with the introduction of coarse material. But if the problem of selecting suitable alluvial clays is attacked in this light it often is possible to find one corresponding to all the requirements.

According to the character of the rock detritus carried along we have alluvial clays of all possible mineral compositions, from almost all sand to practically all clay. In general, however, the alluvial clays used so extensively in brick making range in composition between 25 to 60 per cent. clay substance, 5 to 25 per cent. feldspathic detritus and 0 to 25 per cent. of quartz.

MAP II.



■ Oil or Gas Territory
○ Town
1 2 3 4 5 6 Scale

COUNTIES.
VAN WERT
PUTNAM
ALLEN
AUGLAIZE
MERCER
SHELBY
DARKE
OHIO. 1902

Chemically, the variations are just as wide, and hence it is easy to see that we can have alluvial clays high in lime, or iron, or silica, although as a rule the alumina is never high, due to the fact that the clay substance is usually low.

In the sandy varieties the total silica may be 90 per cent., in the calcareous the calcium carbonate may be 20 or 25 per cent. In the ferruginous clays the ferric oxide may be as high as 10 to 14 per cent.

The following analyses represent typical alluvial clays:

Ingredients.	Sample Number.		
	1	2	3
Silica.....	63.73	74.75	61.93
Alumina.....	17.17	12.55	19.87
Ferric oxide.....	5.85	5.28	7.83
Lime.....	0.58	1.28	1.61
Magnesia.....	0.97	0.85	0.77
Potash.....	2.33	2.27	2.38
Soda.....	0.67		
Chem. water.....	4.90	3.23	5.91
Moisture.....	2.96	.....	.....
% SiO ₂	3.71	5.96	3.12
% Al ₂ O ₃			
Molecular ratio—Silica to Alumina.....	6.31 : 1	10.13 : 1	5.30 : 1

No. 1 is an alluvial clay from Columbia, Ohio.

Nos. 2 and 3 are clays quoted by Langenbeck as typical alluvial clays.

The rational analyses of Nos. 2 and 3 were found to be as follows:

	Per Cent.	
	No. 2.	No. 3.
Clay Substance.....	39.12	67.90
Quartz	52.54	21.57
Feldspathic Detritus.....	8.55	10.83

It is quite obvious that the composition of the clay substance in these clays cannot be as pure as that of refractory clays owing to the heterogeneous character of the mineral fragments from which the clays resulted. In clays Nos. 2 and 3 the clay substance had the following composition :

	Per Cent.	
	No. 2	No. 3
Silica	44.86	48.53
Alumina	30.50	28.48
Ferric Oxide.....	11.71	9.22
Lime.....	1.30	2.14
Magnesia	2.17	1.02
Potash	1.20	1.92
Soda.....		
Chemical Water	8.26	8.70
Ratio, Silica to Alumina.....	1.47	1.70
Molecular Ratio, Silica to Alumina.....	2.50	2.89

Glacial Clays.—The glacial or drift deposits cover at least two-thirds of Ohio in varying thickness.

“The line marking the most southern drift formation enters Ohio in Columbiana county, passes eastward through Stark into Wayne county, turning to the southward as far as Holmes county. From this point its general direction is southwesterly. It leaves the State in Brown county, crossing the Ohio river into Kentucky, a small part of which is included in the drift formation. A number of prominent points can be noted by which the boundary can be well designated. Newark, Lancaster and Chillicothe for examples are situated almost exactly upon the glacial boundary.” (Dr. Edward Orton, Geol. Survey, Vol. VII, Part I, p. 38.)

Where does this material come from? We cannot now enter into a detailed exposition of the story of the drift clays and our explanation must be restricted to the statement that all glacial clays are a conglomerate mixture of native clays, shales, sandstone, limestone and various other rocks mostly of igneous origin, which have been brought from the north by the irresistible sheet of ice once covering so large an area of Ohio. We must keep in mind that the tremendous mass of ice not only ploughed up the old rocks, but also carried along those varied rocks which are peculiar

to northern Michigan and Canada. Besides this the ice, owing to its enormous weight, exerted great pressure on the surface and compacted it.

As is to be expected, the glacial or drift clays of Ohio are a heterogenous material of extreme irregularity of composition, containing boulders of all sizes, sandy at one place and again full of limestone pebbles, besides many other extreme variations. We can reduce our treatment of the glacial clays to the statement that as such they are unfit for consideration as cement materials.

The only way by which they can be made workable by nature is redeposition, which may give rise to local deposits of great value for cement making. The boulder clay must be washed by rivers or creeks into lakes where the fine mineral matter is deposited, giving rise to fine grained clays of more or less uniform composition. If the composition is suitable for the manufacture of Portland cement, having the proper silica-alumina ratio and being low in magnesia, such a clay is of great value and should be carefully explored. Its importance can, however, be only local, since it was deposited in a lake in a given locality under favorable conditions. All these clays have a tendency to be irregular in composition and must be watched carefully in winning them.

The table on page 84 gives analyses of several glacial clays:

Columbus drift clay analyzed by the rational method gave the following result:

	Per cents.
Clay substance.....	33.60
Quartz.....	42.20
Feldspathic matter.....	20.18
Calcium carbonate.....	4.02

SANDSTONE AND SAND.

There may be cases in which the prevailing conditions demand the addition of silica as such to the Portland cement mixture and it may hence become necessary to look for a silicious material. It is evident that such a material must be fine grained and easy to grind if it is to become available for this purpose. The most suitable sandstone has already been mentioned as being an accessory of Bedford shale, namely Berea grit. Of course this stone is not everywhere suitable, it being in places very hard and difficult to grind, while again it may be coarse grained and irregular in composition. The fitness of a stone for cement purposes must be determined for each local deposit. The stone is frequently made more easily reducible by being heated in a vertical shaft furnace built exactly like a limekiln, and quenched while hot by a stream of cold water. It would not be necessary to raise the temperature very high, a good red heat being ample to accomplish the desired result.

Though sandstone may not be available, sand is found in so many localities that a satisfactory kind will be accessible almost every where. It is evident that the sands also differ greatly in physical and chemical

Number	Percentages of Constituents.							Molecular Ratio $\text{SiO}_2 : \text{Al}_2\text{O}_3$
	Silica.	Alumina.	Ferric Oxide.	Lime.	Magnesia.	Potash.	Soda.	
1	69.77	18.33		3.25	0.64	2.74	0.48	6.48 : 1
2	50.70	17.00		9.41 (as carbonates)	4.66	.....	.....	5.07 : 1
3	64.85	17.98	5.92	2.24	1.40	.....	.....	6.12 : 1
4	65.41	16.54	6.06	2.22	.....	0.43	7.46 (Loss)	6.72 : 1

Clay No. 1 is glacial clay dug on the campus of Ohio State University.

No. 2 is clay used in manufacturing Portland cement at Harper, Ohio.

No. 3 is a redeposited lacustral clay used largely in making cement, found at Millbury, Ohio; much of it is shipped to Michigan.

Analysis from Geological Survey of Michigan, Vol. VIII, Part III, p. 229.

No. 4 is leached glacial clay, found at Sandusky, Ohio, and used in making Portland cement. Quoted in Tonindustrie Ztg., Vol. 24, No. 151.

respects and must be examined as to their composition and extent of the deposit. The ideal source of sand would be the material known as molding sand, which is very fine grained, though carrying considerable iron and alumina.

LIME.

A rough classification of lime materials might be made as follows:

1. Crystalline calcium carbonate, crystalline character well developed.
2. Dense, glistening.
3. Dense, dull, non-crystalline, often impure.
4. Amorphous, porous, earthy, often impure.

The gradations from the chemically pure calcium carbonate which was formed under favorable natural conditions to the most impure calcareous materials, like the calcareous clays, are not abrupt. Sedimentation of clayey materials was always coincident with the precipitation of the lime to a greater or less degree, and hence we can look for pure carbonate only in exceptional cases. A good deal of the pure lime is obtained by resolution and precipitation, or by taking up of lime by animal life, resulting in the building up of banks of animal remains (coral banks).

Crystalline Calcium Carbonate.—Calcium carbonate in its state of greatest purity is represented by calcite, whose specific gravity is 2.72 to 2.90. Another form of crystalline calcium carbonate, the aragonite, crystallizing in the rhombic system, has a specific gravity of 2.9 to 3. While on burning calcite calcium oxide is obtained which slakes in water with the evolution of heat, aragonite when burnt increases apparently in volume and breaks up into an asbestos-like matted mass of needle-like crystals. When powdered and moistened with water the substance does not heat, but breaks down slowly to a powder. It is harder than calcite, but more soluble in water.

The principal forms of crystalline calcium carbonate are the coral rocks, the white or grayish coarse-grained limestones, showing the glittering calcite grains very distinctly, the calcareous masses deposited from solution in limestone caves (stalagmites, stalactites), travertine, etc. When metamorphosed by the action of heat and pressure, limestones may be changed by recrystallization to marbles, which are characterized by an extremely uniform grain, giving them a granular structure.

The Dense, Glistening Forms.—The dense, glistening limestone rocks are as crystalline as the preceding materials, but the crystallization is not as well defined and the individual crystals are, as a rule, too small to be identified. These rocks form the most important source of lime for the lime industry, and hence are of much greater economic value than the crystalline rocks of the first section. These limestone occur in massive beds and are extremely dense, producing the greatest amount of caustic

lime per unit volume, but requiring also more heat in the burning. The rocks are liable to be contaminated with varying smaller amounts of impurities and especially may be associated with the carbonate of another alkaline earth, magnesia. But as a rule the clayey impurities are small in amount. On breaking the rocks show a splintery or conchoidal fracture. The specific gravity varies from 2.6 to 2.8. When treated with cold hydrochloric acid it dissolves readily, except in the presence of a larger amount of magnesium carbonate; the clayey matter is practically all left behind. No fixed limits can be drawn for the composition of these rocks; it is bound to vary, depending on the conditions which prevailed during the formation period. If precipitated in muddy water, the limestone is certain to contain clay; if thrown down in concentrated aqueous solutions, as in inland lakes or bays of the sea, other salts like the magnesium compounds are bound to crystallize out with the lime.

Dense, Dull, Non-Crystalline Limestone.—These are principally lime deposits produced in muddy water, and hence are high in clay. It is quite evident that the variety of composition of these materials must be wide, since the impurities and the clayey substances may represent almost any possible combination of materials. As the clayey constituents increase the limestone changes to cement rock and finally merges into a calcareous shale. The rocks of this division are, as a rule, very hard and dense and possess a dark blue or dark gray color. Frequently they show shale structure, caused by mountain pressure. The calcium carbonate is very often associated with magnesium carbonate, so that the rock is really a clayey dolomite. Carbonaceous matter is frequently deposited in these rocks, from graphitic carbon to bitumen and volatile hydrocarbons. Some of the so-called "stink stones" owe their fetid odor to petroleum compounds or to hydrogen sulphide. Limestones of this character are often high in iron sulphide (pyrites), which accelerates the decomposition of the rock by weathering, spoiling it for building purposes.

To the dull, hard limestone divisions belong also the rocks having a concretionary or oolitic structure.

Many sedimentary rocks show a concretionary structure. This may be part of the original sedimentation or may be due to subsequent segregation around a center.* This structure is produced by the collection of mineral matter, say calcium carbonate, from the surrounding rock or from without around some center so as to form a nodule, large or small, as the case may be. If these nodules are close together they may form a practical source of lime, but this is usually not the case. Oolite consists of more or less round grains of calcium carbonate, each grain having been deposited in concentric shells around some center. The oolitic rocks have the appearance of a mass of fish eggs, as, for instance, the well-known Indiana oolitic stone.

*Geikie, *Text Book of Geology*, page 510.

Amorphous Calcium Carbonate.—This forms a large class of materials of great practical importance. Its variety of composition is very great. The most representative materials of this class are chalk and marl. The former is a fine light-colored material derived from the remains of foraminifera, echinoderms and other marine organisms. Owing to its extreme fineness it becomes readily available for chemical reaction. Throughout the chalk-beds flint-stones are found which either have a direct organic origin or have been formed by the precipitation of silica.

The term marl is applied to calcareous materials formed in connection with fresh water lakes or basins by the precipitation of lime, obtained by the leaching out of limestone rocks. Various theories are advanced in regard to the formation of marls, but none of them have been proven beyond doubt, yet the chemical theory seems to come closest to the truth. The extreme fineness of grain of marls renders them especially suitable for cement-making purposes, and hence large manufacturing districts have been built up around the great marl areas of the country. In addition to the fineness of grain of marls, the fact that their calcium carbonate is amorphous is a material factor in bringing about ready chemical combination. The one great drawback is the extreme irregularity of composition, which causes them to show great fluctuations within narrow areas, and hence calls for caution and thorough exploration of newly developed marl deposits.

THE LIME RESOURCES OF OHIO AVAILABLE FOR PORTLAND CEMENT MANUFACTURE.

PRELIMINARY STATEMENT BY PROF. EDWARD ORTON, JR., E. M. AND
S. V. PEPPEL, B. SC.

The resources of Ohio in raw material for the manufacture of Portland cement are great. Fuel, limestone and clay are here in abundance, together with some of the marls which form so important an element in the lime supply of Indiana and Michigan.

The ability of Ohio to furnish limestone of a desirable composition and in quantities sufficient to justify economic development for the manufacture of Portland cement is much greater than is the general belief. Almost all of the Lower Silurian formation above drainage in Ohio is available. Many points on the Clinton horizon furnish beds from 7 to 15 feet thick which are of desirable composition. A few places on the northern portion of the Corniferous limestone may be used for a thickness of from 3 to 7 feet. Several horizons in the coal measures have stone of the proper composition, namely, the Maxville, the Ferriferous and the limestones over the Pittsburg coal horizon, and a small area, 30 to 50 feet, under the Pittsburg coal in Athens county. Twenty-three counties, at some point in each, furnish a limestone which can be made into a good Portland cement, and nearly all of these have quantity sufficient to be worked with economy.

Limestone, or mixtures of limestone and shale within the following limits of composition, will be found to be very close to the composition desired in a Portland cement mixture:

	Per Cents.
Silica.....	15-16
Alumina and ferric oxide.....	6- 7
Calcium carbonate.....	74-76
Magnesium carbonate.....	0- 4.5

The ingredient which we must watch with greatest care is the magnesium carbonate. It must not go much beyond 4.5 per cent., and the lower it is the better. If the silica and alumina are too high, we can correct this by throwing out a little clay or shale or adding a little high-calcium limestone.

Bearing the above statement in mind, a scrutiny of the tables of analyses given later will show that there are many places where limestone of great thickness, mixed with shale in thin strata, the average of which comes very close to the limits named above, may be obtained.

The samples, the analyses of which are given later, were in most cases so taken as to represent a cross section of the strata. A section was

cut so as to approximate as nearly as possible what would be obtained by taking out a core with the diamond drill. The resources of each horizon are given herewith:

LIMESTONES.

Lower Silurian.—The Lower Silurian or Hudson river group consists of layers of shale and limestone interstratified. The shale varies from less than 1 inch in thickness to 4 feet and the limestone from a few inches to 14 feet. It is seldom that two layers are found, one or the other, without a shale parting. The shales are always silicious, with the silica or quartz rather fine grained, which is a desirable feature for Portland cement manufacture. This group of limestones frequently offers faces of 50 to 100 feet with comparatively little stripping. This is the largest single body of limestone in the State, which will make Portland cement. There will be but few localities in this formation, which will not furnish stone of a desirable composition, as the table of analyses will show.

This formation can be found in a few ridges in Miami county, in Preble, Montgomery, Clark, Green, Butler, Warren, Clinton, Hamilton, Clermont, Highland, Brown and Adams counties. The limestone is a dark, blue gray to purple, highly crystalline stone. The shales are blue, gray, and brown. (See table I at the end of the chapter.)

Clinton.—The Clinton horizon is the only other horizon of the older rock formations of the State of much commercial importance for the cement industry. The Clinton is found almost everywhere along the border of the Hudson river groups, and is nearly always overlapped by the next formation above, which is the Niagara. The Clinton is a highly crystalline rock of varied colors, and compositions, and of variable thickness. Sometimes there is a little shale interstratified, but as a rule not. The upper layers are always characterized by the abundance of crinoid fossils. While it is the most irregular of the lower limestone formations, it is readily recognized, and notwithstanding its varied composition quite a number of locations furnish stone of excellent quality for cement manufacture, as is shown in the table of analyses. It frequently happens that the lower beds of this formation are highly magnesian, and it is not uncommon for it to be highly magnesian throughout. At Lumberton, Clinton county, there is 12 feet of stone, with less than 2 per cent. MgCO_3 , lying on top of 5 feet with 29.94 per cent MgCO_3 . At Lynchburg, there is 14 feet 6 inches with a little over 1 per cent. of magnesium carbonate on top of 5 feet with 12 per cent. of MgCO_3 and at Leesburg, Highland county, not many miles from the former location, it varies from 25 to 41 of the MgCO_3 .

The great majority of this stone which is of proper quality is from 7 to 15 feet thick, and so located that if more than 10 to 20 acres were to

be worked it would have to be won by underground mining. The Clinton limestone is to be found in Preble, Montgomery, Clark, Miami, Greene, Clinton, Highland, Warren and Adams counties. (See table II at end of chapter.)

Corniferous.—One sample taken from the Corniferous at White House, Lucas county, showed 7 feet of the top rock to be of a desirable composition. This is a crystalline rock, which is a mass of fossils. The stripping was not excessive here. An analysis made by Lord* of the cap rock at the Kelly Island quarries showed a similar composition. The known localities on the Corniferous horizon where suitable rock can be obtained in quantity sufficient to form the basis of a large cement industry are not abundant. While the lower 40 feet of the Marble Cliff quarries near Columbus gives only 6.06 magnesium carbonate, and it is probable that many layers could be sorted out that would be low enough for Portland cement, it would probably not be profitable to work them for this purpose. It is valuable for furnace flux as it is, and the cost of careful sorting would be considerable, so that the more particular use would be at a disadvantage. (See table III, at end of chapter.)

Maxville.—The first of the Coal Measure limestones met in ascending the geological scale is the so-called Maxville limestone, which lies at the very base of the coal measures, or on the top of the Sub-Carboniferous. The area of the State covered by this stone is not large, nor is its presence at all regular, or constant, over areas in which it does sometimes appear. It appears to have been deposited in lakes or ponds of limited area. So far as known, this does not overlies the Sharon or No. I coal, but rather appears to come in areas where the coal is wanting.

This limestone is found in parts of Hocking, Perry, Muskingum and Licking counties. A line drawn from Logan to Mt. Perry, nearly north and south, would serve as the axis for the known exposures. The furthest point south is $2\frac{1}{2}$ miles below Logan. The furthest north is at Glenford. The largest body of the stone is at Fultonham and White Cottage, where it thickens up enormously for a small area, and becomes 40 or 50 feet thick. Unfortunately, only the top 15 to 20 feet are above drainage at this point.

The quality of the stone is variable. It is occasionally very pure, and free from magnesium carbonate, and eminently suited to cement manufacture. In other places, it is magnesian and worthless. In some places, the stone is composed of some strata suited, and others not suited, to cement manufacture. In such cases, the present analyses are not conclusive, as they represent the average or cross-section of the whole bed. (See table No. IV at end of chapter.)

Mercer.—The next limestones encountered in ascending the scale are the Mercer, Lower and Upper. These stones are usually thin; they

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are dark blue in color, frequently full of globular flint or chert, and very fossiliferous. They are seldom magnesian, but would make a dark cement on account of the carbonate of iron which they usually carry. In a few localities, these stones swell up to workable proportions. One of these is at a point about two miles southeast of Flint Ridge, in Licking county, Ohio, where a 12-foot ledge of favorable composition is visible and could be easily quarried. Another at Somerset, Perry county, 5 feet thick is of the same character. The composition of these stones shows, after careful sampling, as follows:

	Per Cent.	
	Licking.	Perry.
Silica.....	44.54	31.70
Alumina.....	6.78	2.91
Ferric oxide.....	2.20	1.55
Carbonate of calcium.....	43.18	61.75
Carbonate of magnesia.....	1.09	0.83
	97.79	78.74

These would make very desirable stones for mixture with a purer stone, as a means of introducing the necessary silica and alumina.

In the southern part of the State, in Scioto county, on the edge of the territory of the Ferriferous limestone, the Mercer stone undergoes a local thickening at Howard furnace, making a promising material at that point as shown by the following analysis:

	Per Cents.
Silica.....	1.02
Alumina.....	0.62
Ferric oxide.....	1.08
Carbonate of calcium.....	94.85
Carbonate of magnesium.....	0.91
	98.48

As a rule, however, the Mercer stones are too thin and often too cherty to be considered as a possible asset for a cement industry.

Putnam Hill.—The next is the Putnam Hill limestone in central Ohio and the nearly equivalent Ferriferous limestone found in north-eastern and southern Ohio. The area occupied by the two does not overlap, at least has not been shown to do so to any important extent, and at the point where one begins the other is usually dwindled down to a mere trace. Both stones lie close below the lower Kittanning or No. V coal, but they are probably stratigraphically distinct. The works of the Diamond Portland Cement Co., at Middlebranch, Stark county, O., are sup-

plied from an opening in the Putnam Hill limestone, which is there 8 feet in thickness. The following is the composition of the stone:

	Per Cent.
Silica.....	4.12
Alumina.....	1.86
Ferric oxide.....	1.20
Carbonate of calcium.....	91.16
Carbonate of magnesium.....	1.63
	99.97

Localities where this stone is of suitable composition are not rare, but no other locality can be cited where the stone assumes a thickness at all sufficient for any extensive cement industry. It is usually of dense gray limestone, of 2 to 4 feet in thickness, which could not be profitably mined or stripped.

Ferriferous.—The Ferriferous limestone, especially in its southern exposure, is a very important and promising source of cement stone. The area covered by this stone, in its exposures above drainage, comprises an area about 6 to 8 miles wide and 40 or 45 miles in length, and amounting to about 300 square miles. In the western edge of this area, it is too thin to mine well, and its position near the tops of the hills makes the areas small. But on the eastern edge the areas are large, and but little dissected by valleys, and the stone is covered by strata suitable to make a good roof for mining it. Its thickness runs from 4 feet in the thin exposures to 10 feet in the best; 6 to 8 feet are its usual development. It can be won by mining or by stripping and benching around the edges of the hills. The point where the latter method ceases to be profitable marks the point where mining becomes possible. The chemical character of the stone is exceptionally well suited to cement manufacture. It is low in magnesium everywhere; it is usually well over 90 per cent. of CaCO_3 and frequently contains over 95 per cent. of this ingredient. Its iron is generally low, favoring a light colored cement. • (See table V at end of chapter.)

This stone is now being used as the basis of cement manufacture at some three well equipped works, which are turning out an excellent product.

This stone on the northern edge of its field becomes thin and irregular and finally disappears north of Creola, Vinton county, and shortly afterwards the Putnam Hill limestone makes its appearance, in passing to the northeast.

Lower Kittanning.—There is no other constant or well marked horizon of limestone of which sufficient quantity is found to be commercially interesting for several hundred feet above the Ferriferous horizon. Several formations swell up locally and offer for a limited area a

possible source of cement supply. Of such a character is the stone at Lisbon, Columbiana county, where it has been used as the basis of a "natural cement" industry for years past. It is only 34 inches thick, occurring on the horizon of the lower Kittanning coal. It analyzes as follows:

	Per Cent.
Silica.....	17.76
Alumina.....	7.94
Ferric oxide.....	1.86
Calcium carbonate.....	66.25
Magnesium carbonate.....	2.82
	96.63

Middle Kittanning.—A similar stone at Rodgers, in the same county, having a thickness of 4 feet 6 inches, has the following composition. It is obtained just under the middle Kittanning.

	Per Cent.
Silica.....	25.44
Alumina.....	10.62
Ferric oxide.....	2.34
Calcium carbonate.....	55.59
Magnesium carbonate.....	2.14
	96.13

Both of these stones are won by mining.

Freeport.—The Freeport limestone occurring on the horizon of the coal veins of that name are generally very impure, either being cherty, or clay like. No instance is known to the writers where this stone seems promising.

Cambridge.—The Cambridge limestone, located approximately 100 feet above the Freeport horizon, through a well marked horizon so far as regularity and persistence is concerned, is generally thin and worthless for the present purpose. Like most of the coal measure limestones, its origin favored its occasional growth into relatively thick pockets and masses, but usually it is a thin layer, even degenerating into a stratum of boulders separated by clay. At Cambridge, in Guernsey county, it is reported as of 8 feet thickness and as having been worked for lime. It is certainly not a wide or important formation for this use.

At the head of Cannon's Creek in Lawrence county, the Cambridge stone thickens up into a ledge of some 6 feet or so, quite cherty in character. A careful cross-section of this exposure analyzed as follows:

	Per Cent.
Silica.....	38.00
Alumina.....	6.78
Ferric oxide.....	1.90
Calcium carbonate.....	50.60
Magnesium carbonate.....	1.73
	99.01

This would of itself be of no great importance, but its proximity to the great Ferriferous limestone areas, where 94 per cent. lime is available, makes it worth considering as a source of the silica and alumina needed for the cement. The silica, being in the amorphous form, and mixed with its own lime, would make it ideal for that purpose.

At Albany, Athens county, the same horizon, or possibly the Freeport, furnishes a 7-foot 6-inch ledge of stone of the following composition:

	Per Cent.
Silica.....	50.30
Alumina.....	5.46
Ferric oxide.....	1.20
Calcium carbonate.....	40.91
Magnesium carbonate.....	1.36
	99.23

Here again the stone would be available as a mixture, but not by itself.

Crinoidal.—The Ames or Crinoidal limestone, located about 100 feet above the Cambridge and approximately 100 feet below the Pittsburg coal, is in general much like the Cambridge in its general character and occurrence. It is usually thin and worthless, except as a stratigraphical guide, in which its persistence and fossiliferous character make it of great value. In one area only, viz., west and southwest of Wellsville, Columbiana county, extending into the northern part of Jefferson county, is the Ames or Crinoidal thick enough to be of interest. A few square miles of country shows it there in ledges of from 6 to 8 feet thick. The following sample, taken near Wellsville, shows what may be obtained:

	Per Cent.
Silica.....	6.50
Alumina.....	1.87
Ferric oxide.....	0.71
Carbonate of calcium.....	87.90
Carbonate of magnesium.....	1.20
	98.18

The large limestone deposits of the coal measures are found above the Crinoidal limestone, but in horizons of very uncertain and fluctuating character.

Pittsburg.—These limestones begin occurring at a point about 50 feet above the Crinoidal limestone, or about an equal distance below the Pittsburg coal. This horizon furnishes what is called the Pittsburg limestone in some places. Passing upwards, another well developed calcareous belt occurs just under the Pittsburg coal, and another immediately over. The upper one is frequently spread out over 50 feet or more of strata. In fact,

limestones may be found, at some point, almost all the distance between the Pittsburg and Meigs Creek coal. By far the largest and most representative veins, however, are those which lie close to the coals.

All these horizons furnish local veins of sufficient thickness for economic quarrying or mining. But the usefulness of these deposits is undoubtedly much reduced by the fact that they do not appear to be well defined over large areas. In fact, within the limits of one section, it is not uncommon to find a stone cutting out and being replaced by shales, clays, or even sandstones, so that they may be regarded as lenses, or swamps, rather than persistent and well defined deposits, like the limestones of the lower measures.

Nevertheless, these swamp deposits, while not uniform enough to make them valuable as stratigraphic guides, are in many places amply large to make them of possible economic value. In many places they cover a number of square miles, and thus offer all necessary opportunity for permanent industrial development.

The analyses of samples taken from these veins are confined here to those which were found promising for this purpose. In many other points which were examined, the percentage of magnesia was found too high for cement work. The method of sampling employed was to cross section all the strata available for quarrying at the point sampled, so that the average composition of the entire mass might be known. This method has the merit of giving a broad view of the composition of the strata, but has the fault of oftentimes condemning the deposit, on account of the deleterious influence of some comparatively small stratum. Thus, it may very likely be found on further closer examination that the magnesia in many of the areas will be found concentrated in portions of the bed, and that a now unpromising vein may be made to yield a considerable portion of stone of excellent quality. This list is therefore far from final as regarding the economic areas of stone of this district. The fact that such good results have been gotten in some places should lead the cement prospector to look much more carefully into this territory in the future, and determine for each locality whether the magnesia contamination is local or general. A tabular statement of analyses of these upper limestones is given in Table VI.

MARL.

The bulk of the supply of calcareous materials in the State is in the hard and geologically ancient form of limestone. But there is also to be considered the soft recent deposits known as marls.

These marl deposits occupy chiefly the beds of lakes or ponds. In most cases in Ohio, the lakes have been drained or dried up, so that the marl occupies a flat meadow, more or less covered over with soil and

humus. But in Indiana and Michigan, large lakes are still in existence, though much shrunken in area, whose banks and bottom are covered with the marl. In some cases, extensive operations are undertaken to drain these lakes to get at the marl and in other cases the use of dredges is resorted to bring it up from the bottom.

The origin of the marl has been discussed a great deal. It is now ascribed to the action of fresh water algæ, which precipitate it or throw it down from solution. Whether this be the truth or not, its close and intimate connection with fresh water lakes is too patent to be denied. In searching for it, therefore, the obvious method is to observe the locality for flat meadows or marshes, which have the appearance of having been at one time the site of glacial lakes. The water sheds between the rivers flowing north to the lakes and south to the Ohio forms a promising territory for such explorations, but many of these marl covered lake-sites exist all through the drift covered area of the State, more abundantly in the northwestern third.

The composition of the marl is eminently well suited to cement. It consists of the amorphous or organic form of calcium carbonate, mixed with varying amounts of soil, sand, humus, snail shells, etc. Frequently the percentage of calcium carbonate reaches 96 to 98 per cent., while magnesia, the bane of Portland cement, is practically absent. It is a soft, damp, gray earth somewhat like bulk sugar in appearance; it has little plasticity when worked up with water like a clay, and still less hardness or strength when dried. It dissolves in any acid, even vinegar, with much effervescence or foaming. Many farmers, owning land on which it occurs, do not know what it is, or of its possible uses; others do not care to sell their land for cement purposes, as these old swamp beds are usually rich and productive for farming.

Ohio's known areas of marl are very limited compared to those of Michigan and Indiana. It is not probable that any future discoveries will bring our deposits up to theirs in size or importance. But it is wholly probable that our resources can be greatly extended by systematic and intelligent search. Nothing of the sort has been yet undertaken. A two inch boring auger, with extensible handle, is about all the equipment that is needed, as these deposits are always superficial and under but slight cover of clay or soil. By driving over the country, studying its topography, searching out its old depressions, and drained marshes, it would be possible without doubt to bring many deposits to light.

The marl beds of northwestern Logan county, lying between Harper and Rushsylvania, are typical deposits. These deposits support two Portland cement industries, the Buckeye and Alta plants. An analysis of the marls shows:

	Per Cent.
Silica.....	8.75
Alumina.....	2.78
Ferric oxide.....	
Carbonate of calcium.....	79.21
Carbonate of magnesium.....	2.67
	93.41

This analysis is characteristic, though the amount of clay mixed with the marl causes its proportion of silica and alumina to rise a little at the expense of the carbonate of lime from time to time. As clay must be added in any case, this is no disadvantage except possibly in keeping uniform mixtures. The known extent of this field is not great and is under control of the two companies now established.

Another marl area is in northeastern Sandusky county and northwestern Erie county. The Sandusky Portland Cement Co., located at Bay Bridge, has nearly exhausted its bed of marl which was not of large proportions originally. It has supplied material for a considerable industry for more than a decade. The Castalia Portland Cement Co., at Castalia, three or four miles south of Bay Bridge, has a much larger bed and a larger plant.

Travertine.—Associated with the marl beds in the Castalia district is a layer of Travertine, or calcareous tufa, deposited probably from former overflows of the great Castalia spring, which wells forth in volume sufficient to make a small stream. This underground river, for it is nothing else, maintains at present a considerable lake or pond, and in times past probably made a much larger area of swamp land. Over this area, the travertine has been deposited, in some places as much as three or four feet thick, though generally much less. It is substantially pure carbonate of lime, showing a content of 99.4 per cent calcium carbonate.

It is deposited as carbonate, from the breaking down of calcium bicarbonate as it emerges from the underground water-course, and is exposed to the air, heat and motion of the stream. Though travertine can hardly be called a regular source of Portland cement material, it is used at the Castalia works with very excellent results.

TABLE I.—Analyses of the Limestones.

Serial number of sample.	Locality of Quarry.	Thickness and relative position of stratum represented by this sample.
83	Adams Co., Manchester.....	From top layer down 21 feet.....
84	“ “ “.....	Next 12 feet below sample 83.....
85	“ “ “.....	From water level, up 20 feet.....
86	Brown Co., Georgetown ...	From top layer, down 16 feet, 6 inches.....
87	“ “ “.....	Next 23 feet below sample 86.....
88	“ “ “.....	Next 50 feet below sample 87.....
89	“ “ “.....	Next 26 feet below sample 88.....
90	“ “ “.....	Next 30 feet below sample 89.....
66	Butler Co., Excello.....	From top layer, down 10 feet 6 inches.....
65	“ “ “.....	Next 10 feet 6 inches below sample 66.....
58	“ “ Hamilton.....	From top layer, down 11 feet.....
59	“ “ “.....	Next 15 feet below sample No. 58.....
57	“ “ “.....	Next 15 feet below sample 59.....
56	“ “ “.....	Next 8 feet 6 inches below sample 57.....
55	“ “ “.....	Next 11 feet below sample 56.....
91	Clermont Co., Bethel.....	From top layer, down 18 feet.....
78	“ “ “ New Richmond	From top layer, down 20 feet.....
79	“ “ “.....	Next 15 feet below sample No. 78.....
76	Hamilton Co., Cincinnati. .	From top layer, down 8 feet.....
72	“ “ “.....	Next 18 feet below sample 76.....
73	“ “ “.....	Next 17 feet below sample 72.....
74	“ “ “.....	Next sample below sample 73.....
75	“ “ “.....	Next 13 feet below sample 74.....
77	“ “ “.....	From 85 to 107 feet from top of quarry. .
92	“ “ “.....	Next 22 feet below sample 77.....
93	“ “ “.....	Next 19 feet below sample 92.....
71	“ “ Glendale. .	From top layer, down 25 feet.....
70	“ “ “.....	Next 40 feet below sample 71.....
69	“ “ “.....	Omitting 3 feet, next 20 ft. below sample 70.
68	“ “ “.....	Next 11 feet below sample 69.....
67	“ “ “.....	Next 13 feet below sample 68.....
54	Preble Co., Camden.....	From top layer, down 10 feet.....
53	“ “ “.....	Next 20 feet below sample 54.....
52	“ “ “.....	Next 20 feet below sample 53.....
51	“ “ “.....	Next 12 feet 6 inches below sample 52.....
50	“ “ “.....	Next 12 feet 6 inches below sample 51.....
103	Warren Co., S. Lebanon....	From top layer, down 50 feet.....
102	“ “ “.....	Next 40 feet below sample 103.....

TABLE II.—Analyses of the Limestones

94	Adams Co., Newport.....	From top layer, down 21 feet.....
95	“ “ “.....	Next 10 feet below sample 94.....
L-2	Clark Co., New Carlisle. .	Average of quarry.....
110	Clinton Co., Lumberton....	From top layer, down 12 feet.....
115-116	“ “ Lynchburg.....	From 8 feet 6 inches to 14 ft. 6 in. below top.
131	Greene Co., New Jasper....	From 5 feet to 12 feet below top.....
L-1	“ “ Osborn.....	Best Rock.....
L-2	“ “ “.....	Rejected Rock.....
L-	Miami Co., Piqua.....	Surface.....
47	Montgomery Co., Centerville	From top layer, down 9 feet.....
60-63	Preble Co., Eaton.....	From 2 ft. 4 in. to 14 ft. 10 in. below top..
35	“ “ New Paris.....	From top layer, down 2 feet.....

of the Lower Silurian or Hudson River Formation.

Constituents.					Total.	Remarks.	Serial Number of Sample.
Silica.	Alumina.	Ferric Oxide.	Carbonate of Calcium.	Carbonate of Magnesium.			
9.30	3.04	1.30	82.50	1.93	98.07	A gap between samples 84 and 85 was not sampled.	83
10.10	3.14	1.30	83.50	1.51	99.55		84
7.86	2.95	0.75	85.60	2.48	99.64		85
13.20	4.46	1.30	78.05	2.36	99.37	Total section sampled was 145 feet 6 inches.	86
32.80	9.12	2.30	49.69	4.12	97.99		87
32.34	8.69	2.45	50.00	4.15	97.63		88
31.60	10.97	2.85	47.25	5.00	97.67		89
45.36	15.24	3.90	26.25	5.06	95.81		90
28.94	10.00	2.90	52.95	2.65	97.49	10 feet from bottom of 65 to drainage.	66
31.80	10.95	3.25	48.40	3.25	97.65		65
36.00	12.36	3.70	41.60	3.57	97.23		58
29.96	9.55	3.05	49.80	3.06	95.42		59
33.86	11.56	3.50	44.00	3.72	96.64		57
26.10	8.44	2.30	56.80	3.58	97.22		56
34.80	11.62	2.80	42.50	4.72	96.44		55
18.74	6.80	1.90	68.50	3.06	99.00	Near top of H. R. Formation.	91
38.80	14.64	4.10	35.00	3.07	95.61		78
22.70	9.00	2.00	60.40	3.13	97.27		79
33.50	12.00	3.70	43.35	2.65	95.20	A gap of 12 feet was not sampled between Nos. 75 and 77.	76
20.66	7.74	2.10	63.70	3.58	97.78		72
30.28	10.30	2.40	49.60	4.46	97.04		73
33.08	10.78	2.80	46.60	4.19	97.45	Section represented in full is 148 feet thick.	74
30.00	9.80	2.30	51.45	3.75	99.30		75
36.84	11.14	3.30	40.90	4.15	96.33		77
38.00	13.80	2.80	38.72	3.80	96.62	A gap of 3 feet 65-68 feet below top of quarry was not sampled.	92
25.04	9.38	2.80	58.08	3.02	98.32		93
24.26	7.99	2.65	60.40	2.80	98.10		71
29.80	10.05	2.55	50.95	4.40	97.75		70
38.30	13.35	3.65	35.90	4.84	96.04		69
31.30	11.47	3.25	45.00	6.10	97.12		68
52.38	18.64	4.60	13.20	5.36	94.18		67
9.70	4.31	0.85	80.40	3.09	98.35	Total rock face-sampled, 75 feet.	54
15.28	6.05	1.25	70.35	5.34	98.27		53
13.16	5.15	0.75	75.90	3.30	98.26		52
14.60	5.25	1.55	72.30	4.37	98.07		51
11.62	4.84	0.80	76.70	4.54	98.50		50
23.30	9.11	2.05	60.08	3.28	97.82	Total rock face sampled, 90 feet.	103
29.00	9.57	3.15	52.63	3.52	97.87		102

of the Clinton Formation.

14.80	5.62	2.34	71.40	3.87	98.03	Average.	94
16.84	1.78	1.36	76.80	2.64	99.42		95
0.70	0.41	.....	97.14	1.21	99.46		L-2
1.80	0.85	0.75	93.90	2.78	100.08		110
11.03	0.92	0.82	85.96	1.11	99.85		115-116
9.30	4.38	0.60	81.92	3.24	99.44		131
1.64	0.36	.....	97.09	0.82	99.81		L-1
0.83	0.29	.....	96.80	2.07	99.99		L-2
0.45	0.26	.....	95.03	4.35	100.09		L-
4.02	2.28	0.52	88.95	3.59	99.36		47
0.81	0.82	0.24	94.21	3.79	99.89	Average.	60-63
1.52	1.00	0.60	95.10	1.80	100.02		35

TABLE III.—Analyses of the Limestones

Serial number of sample.	Locality of Quarry.	Thickness and relative position of stratum represented by this sample.
3	Franklin Co., Columbus.....	From 14 ft. 8 inches to 53 ft. below top.
L-1	“ “ “ “	Siftings from crusher, run of quarry.
22	Kelly's Island.....	Extra Cap Rock.
	Lucas Co., White House.....	From top laver, down 7 feet.

TABLE IV.—Analyses of the Limestones

1	Perry Co., Fultonham.....	Top 12 or 15 feet, to water level.
61	“ “ White Cottage...	Top 9 feet, 3 feet to water level.
54	“ “ Maxville.....	White or gray stratum, 4 feet thick.
53	“ “ “ “	Top or Building Rock, 2 feet thick.

TABLE V.—Analyses of the Limestones

—	Jackson Co., Cornelia Fce. ..	Average of 16 Analyses.....
14	“ “ Kitchen Sta. . .	Cross section of stratum, 7 feet.....
35	Lawrence Co., Bartles St. . .	Cross section of vein, 7 feet 6 inches.....
—	“ “ Cal. Hollow... ..	From Campbell's quarry.....
—	“ “ Eliz. tp.	Burke's Mine. Furnace Co.'s Analysis.....
—	“ “ “ “	Holly's Mine. Furnace Co.'s Analysis.....
—	“ “ “ “	Riley's Mine. Furnace Co.'s Analysis.....
—	“ “ Hang. Rock . .	Books of H. R. Iron Co.'s Furnace.....
—	“ “ “ “ ..	Burgess tract, average of ten analyses.....
—	“ “ “ “ ..	Bradshaw Entry.....
—	“ “ “ “ ..	School House Entry.....
—	“ “ Hog Run.....	Section 25. Furnace Co.'s Analysis.....
33	“ “ Olive Fce.....	Cross section of vein, 6 feet 9 inches thick....
—	“ “ Peter Cave . .	Mines of E. B. Willard.....
—	“ “ Pine G. F'ce..	Hanging Rock Iron Co.....
37	“ “ Steece P. O... ..	Cross section of vein, 6 feet 6 inches thick....
38	“ “ “ “	Screenings from crusher.....
180	Mahoning Co., Lowellville..	From top layer, down 14 feet.....
179	“ “ “ “	Next 5 feet below sample 180.....
19	Scioto Co., Eifort Sta.....	Cross section of vein as mined, 5 feet thick....
20	“ “ “ “	Drillings from Power Drill Holes.....
—	“ “ “ “	Average of 9 Analyses, Alma Cement Works..

TABLE VI.—Analyses of the Limestones

141	Athens Co., near Amesville..	14 feet 6 inches thick above Crinoidal.....
36	“ “ “ “	13 feet thick, above Pittsburgh Coal.....
143	“ “ Canaansville.....	14 feet 6 inches thick, above Pittsburgh Coal .
172	Belmont Co., Henrysburg....	7 feet thick, above Pittsburgh Coal.....
153	Guernsey Co., Cumberland ..	7 feet thick, under Meigs Creek Coal.....
176	Jefferson Co., Steubenville... ..	12 feet thick, above Crinoidal limestone.....
139	Washington Co., Wesley Tp.	15 ft. 6 in. thick, above Pittsburgh Coal.....
140	“ “ “ “	11 feet thick, above Pittsburgh Coal.....

of the Corniferous Group.

Constituents.					Total.	Remarks.	Serial Number of Sample.
Silica.	Alumina.	Ferric Oxide.	Carbonate of Calcium.	Carbonate of Magnesium.			
2.30	0.70	trace	91.66	6.06	100.72		3
2.63	0.83	.....	89.23	6.56	99.25		—
0.85	0.27	.....	97.28	2.00	100.40		L-1
1.24	0.69	0.05	95.25	3.47	100.70		22

of the Subcarboniferous Formation.

2.80	1.16	.....	92.80	2.13	98.89		1
3.04	1.54	0.40	92.92	1.21	99.11		61
6.14	1.40	0.40	90.96	0.90	99.80		54
16.34	1.70	1.00	80.35	0.68	100.07		53

of the Lower Carboniferous Formation.

.....	.....	.....	80.90	.....	.....		—
13.62	2.45	.....	82.30	0.82	99.19		14
0.74	0.24	1.30	97.35	0.33	99.96		35
0.98	2.15	.....	94.65	1.84	.....		—
0.41	0.86	0.78	93.28	4.66	.....	SO ₂ 0.78	—
1.30	0.86	.....	By diff	3.81	.....	SO ₃ 0.44	—
0.52	0.80	.....	94.19	4.49	.....		—
0.76	.....	.....	96.87	.....	.....	P=trace.	—
3.30	6.20	with Al ₂ O ₃	88.50	0.75	.....		—
0.76	1.50	with Al ₂ O ₃	96.83	0.84	.....		—
1.10	3.20	5.25	88.70	1.60	.....		—
1.96	.....	1.98	91.32	0.91	.....		—
1.52	1.86	0.70	95.40	0.53	100.01		33
0.23	0.50	1.30	96.83	1.00	.....		—
1.00	1.00	2.00	94.30	1.53	.....		—
3.26	0.90	1.30	94.16	0.85	100.47		37
22.26	1.05	1.55	75.07	0.20	100.13		38
2.58	0.68	0.70	93.50	1.64	99.10		180
2.20	0.54	0.4	94.69	0.71	98.84		179
1.76	2.03	.....	94.50	0.80	99.09		19
0.53	1.55	.....	95.62	0.81	98.41		20
.....	.....	.....	93.50	.....	.....		—

of the Upper Carboniferous Formation.

4.62	1.44	1.00	90.90	1.60	99.56		141
22.90	8.17	2.07	62.29	2.69	98.12		136
14.50	4.56	1.40	76.78	1.21	98.45		143
3.14	0.74	0.90	92.48	1.84	99.10		172
7.24	1.48	1.20	87.47	2.40	99.79		153
12.50	10.11	4.19	61.10	5.86	93.76		176
25.28	8.47	1.87	58.17	3.70	97.49		139
14.32	4.82	1.66	73.67	5.20	99.67		140

CHAPTER III.

THE CHEMICAL AND PHYSICAL EXAMINATION OF CEMENT MATERIALS.

This subject will be taken up in the order of the classification adopted in the beginning. In treating the various methods of examining the materials we must bear in mind that we are to distinguish between scientifically exact and technical methods. Though the first are of great value in their place, they cannot be followed very closely in practice where rapidity is one of the great considerations. We must therefore keep this fact well before us. Another fact to be realized is the close connection between certain chemical and physical methods which go hand in hand and bring to light important relations which are not brought out by chemical or physical methods alone.

Prospecting and Sampling.—In investigating a new property for cement raw materials, it must be realized that the best methods of examination are of no value whatever unless the samples analyzed represent truly the character of the deposit. The guiding principle should invariably be that the less homogeneous a deposit is, the more samples must be taken and the more carefully must the work be done. The writer could cite a considerable number of examples where neglect to make a proper preliminary examination has resulted in the ultimate loss of thousands of dollars. Investors who are willing to put enormous capital into new plants often seem unwilling to spend a few hundred dollars for a preliminary mineral survey of the property. It is difficult to sympathize with such people thus rushing into financial disaster.

There seems a feeling, almost general among a certain class of small capitalists and business men, that the advice of a technically trained expert is either unsafe or unnecessary or both. Large financiers have gotten well beyond this stage and seldom move in any mineral enterprise until all has been done that the best and most skilful mining engineers can do, in disclosing the facts and prospects. But the business man who has made a little money in his own line, in which his judgment is skilled, seems imbued with an equal confidence in his judgment in some other field of which he knows nothing. The mineral industry, which above all others requires close and accurate technical supervision to attain, is the most favored field of these inexperienced and self-confident investors, and the loss annually suffered in this way from ignorant and ill-advised investment is simply beyond belief.

Strangely enough, the opinions of men who are obviously crude and ignorant, and whose opinions would carry no weight in any other connection, are often taken in establishing mineral industries, on the basis of their *practical experience*, while that of trained experts is condemned as *theoretical*. Even the word of interested persons, not possessing a rudimentary knowledge of technical matters, is readily believed by otherwise well-balanced conservative business men. The American habit of "booming" towns and localities has had a great deal to do with this reckless kind of work.

In looking for a suitable clay material the experienced prospector makes use of all natural and artificial excavations, such as gullies, river banks, railroad cuts and quarries, for determining the character of the rocks in a certain locality. He watches every clay outcrop, and by applying the rudiments of geological knowledge is usually able to trace down the available clay beds. With the help of the geological reports and maps, and especially with the assistance of the excellent topographical survey maps of the U. S. Geological Survey, the method of the attack is easily outlined.

If a random sample of a clay outcrop has shown a satisfactory composition and is promising in regard to its physical characteristics, an opening should be made into it, removing the surface clay, and a sample taken from the material within the bank. If this should likewise prove satisfactory, the bed is attacked at several places, examined, and finally a survey is made of a tract which affords enough material for the capacity of the factory which it is intended to erect. The area of the land is plotted and a topographical survey made. Now the map is divided into squares whose sides should range between 50 and 100 feet in length, depending on the different thicknesses of the deposit. If the latter is thick, say 30 or 40 or more feet, the square should be taken with sides of about 50 feet in length; if it is but several feet deep, they should be 100 feet, since the area to be examined in this case is so much larger. At the center of every square a test hole is sunk and the material brought up by the drill put aside for analysis. If at the depth drilled the clay is apparently of the same structure, color and general appearance, a sample need only be collected for every ten feet of depth; if, however, on drilling, various materials are found, a sample must be set aside for each different material.

By means of these drill holes sections can be plotted cutting the center of the area at right angles, one section passing through the deposit, say from east to west, and the other from north to south. After having plotted these sections to scale on a map the total amount of the different kinds of clay available, in cubic feet or cubic yards, can then be calculated with sufficient accuracy.

It is hardly necessary to state that the samples must be kept in suitable, tight receptacles, carefully labeled.

CONTOUR LINES REPRESENT DIFFERENCES IN LEVEL OF FIVE FEET

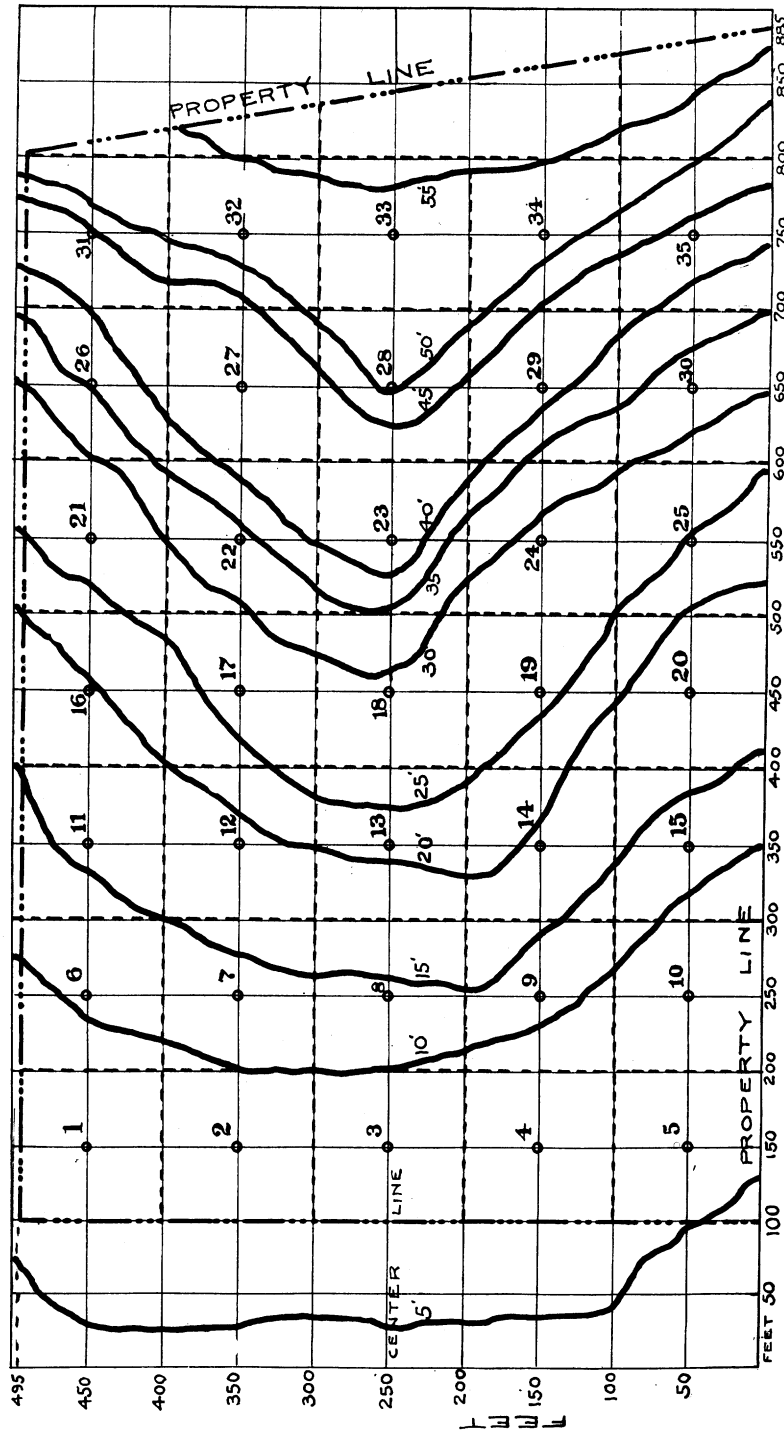


Fig. 7. Map of a property for the purpose of prospecting for clay.

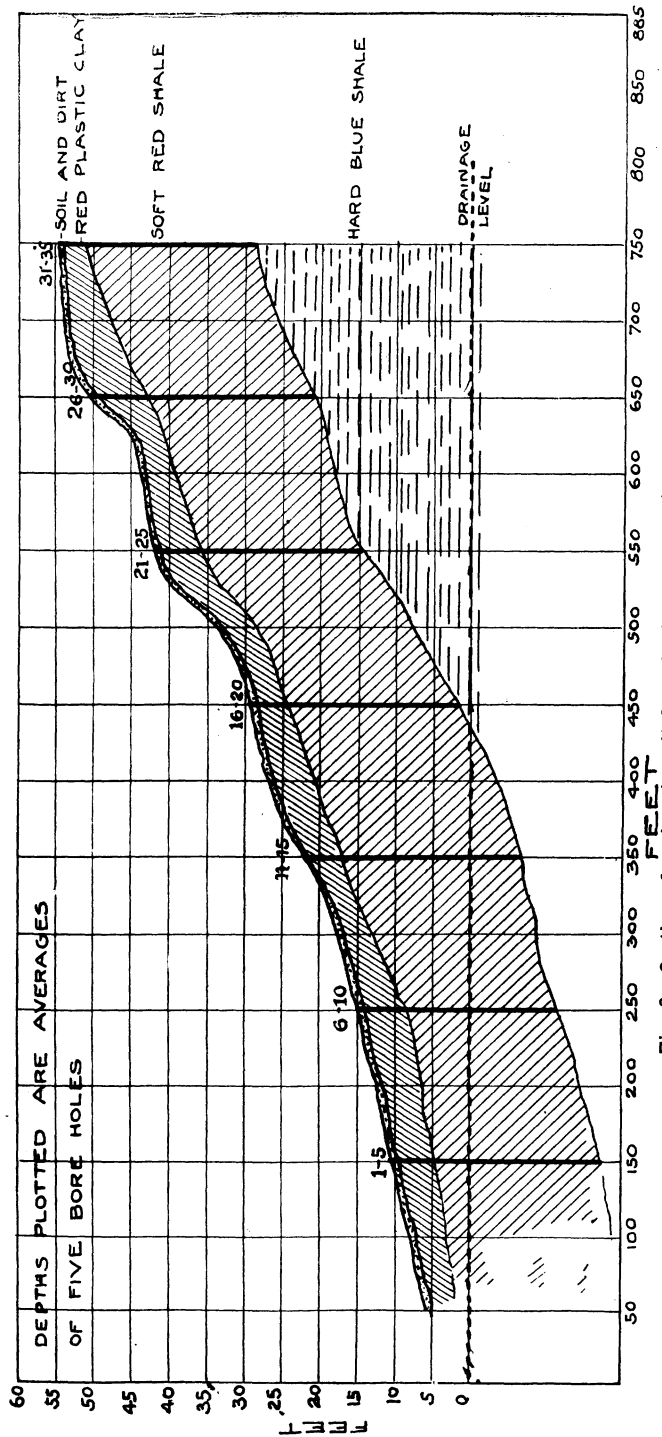


Fig. 8. Section of a clay deposit from borings represented in Figure 7.

The accompanying cuts illustrate this method of prospecting; the section shows the presence of soil, soft clay, soft red shale and hard blue shale.

Assuming that analysis has shown the soft red shale to be the most suitable and finding an average depth of 20 feet of this material, we evidently have available in each square of 50 feet, $50 \times 50 \times 20 = 50,000$ cubic feet of clay. But this procedure has not only shown the amount of clay available, but also the variations in composition, since two samples are taken from a depth of 20 feet. This point should be well considered, as a knowledge of the composition of clays not only gives the prospective manufacturer accurate and valuable data, but is also of great help when manufacturing has been begun, since it tells the chemist what to expect in the future and may prevent some costly mistakes. When this is duly weighed, it surely ought to remove the last prejudice against the expenditure of the money necessary to carry on the preliminary survey.

METHOD OF DRILLING IN CLAY DEPOSITS.

In the prospecting of clay property, the samples required can be obtained either by digging down through the strata to be examined or by drilling holes. It is evident, of course, that by digging prospecting holes, the samples obtained will be large in amount and permit of sampling the deposit in the most thorough manner, and ultimately this must be done in every clay deposit even though only in, say, half a dozen places, at the extremities of the land available and in equal intervals between them. However, the cost of digging the holes is not inconsiderable and would not be resorted to until one is quite sure of his ground. Drilling, being so much cheaper, should be carried on during the preliminary survey, and it may be done as follows:

1. Boring with an auger. Applicable to clays which are free from stones and the softer grades of shales.
2. Drilling with the churn drill.
3. Combination of churn drill and auger.
4. Core drilling, with a serrated pipe, applicable to rather soft material only.
5. Core drilling with a pipe with sharpened edge at bottom, driven down.
6. Combination of churn drill and pipe drill.
7. Marl sampler, used in quite soft materials.

Auger.—The auger is the most successful implement in the exploiting of clay and shales and should be used much more extensively than it is. A good two-inch auger of best quality will answer in many cases.

Catlett* describes an auger which he has used in his prospecting work and which has given good service. The bit is made of steel or

**Trans. Am. Inst. Mining Eng.*, 1897.

Swedish iron with a steel point twisted into a spiral, with an ultimate diameter of 2 inches and a thickness of not less than one-fourth of an inch. The point is more effective when split. The auger proper should not be more than 13 inches long, having four turns. This was welded on to the end of 18 inches of one-inch wrought iron pipe, on which screws were cut for connection.

Churn Drill.—The churn drill, used universally in quarries and wherever hard rocks are to be penetrated, is a most effective tool. It is usually made as a heavy iron rod with a piece of steel at the end about 12 inches long, the cutting edge being about 2 inches. Its use is unnecessary in soft materials, but becomes imperative in hard rocks. In connection with the auger it forms a most useful combination, since it is used when going through hard rock and as soon as clay is reached the auger again becomes available. Such a drill was used by Mr. Catlett in connection with the auger described above. It was made of $1\frac{3}{8}$ -inch octagonal steel with a two-inch cutting face, which was likewise welded on to 18 inches of pipe cut for connections.

In addition other parts are found necessary: Ten feet of $1\frac{1}{4}$ -inch iron pipe, threaded at either end for connection with one-inch pipe. When connected with one of the drill bits this becomes a jumper for starting holes through hard material. It is also used when desired to give additional weight to the drill in going through rock. There are also needed sections of one-inch pipe and connections. An iron handle must be used with a total length of two feet, arranged with a central eye for sliding up and down the pipe and with a set-screw for fastening it at any point. Other accessories are a sand pump consisting of one or two feet of one-inch pipe with a simple leather valve and a string for raising or lowering it, two pairs of pipe tongs or two monkey pipe wrenches; as well as sundries: 25 feet of tape, oil can, flat file and a water bucket.

The auger is worked by two men, turning it by means of the handle, and enough water is used to soften the material. Usually the auger brings up some material which is dry and unaffected. Every few minutes as the auger becomes full it is lifted out, scraped off and put down again. The handle is moved up and tightened by means of the set screws as the auger goes down.

Auger and Drill.—When hard materials are encountered the auger bit is screwed off and the drill bit screwed on, thus forming a churn drill, which may be used for passing through the hard material, the auger being replaced as soon as the softer material is reached. The drill is used as seen in every quarry by being lifted and let fall, it being slightly turned at every stroke.

Mr. Catlett found that the best work was done on soft material, though no difficulty was experienced in going through hard rock. The cost increases materially at a depth of over 50 feet, but it is readily possible

to go down 80 feet and more. Down to 25 feet two men can operate it; from that to 50 feet a rough frame 15 to 20 feet is needed for the third man to stand on. Above 50 feet it is necessary to take off one or two of the top joints each time the auger or drill is lifted.

It is interesting to note Mr. Catlett's observations on drilling some holes, which might form a basis for the calculation of the approximate cost of drilling.

Record of Bore Hole.

	Feet.
Light yellow clay.....	14
Solid iron ore.....	3
Yellow clay.....	1
Solid ore.....	5.5
Yellow clay.....	1
White clay.....	1.5
	26

The above was put down by two men at work for six hours.

The following was put down by two men at work 15 hours and three men for 4 hours:

	Feet.
Red sand and sandstone.....	19
Yellow clay.....	3
Light yellow clay.....	8
Dark yellow clay.....	6
Black clay.....	2
Light yellow clay.....	2
Light yellow clay and black streaks.....	10
Light brown clay with white flint.....	2
	52

Serrated Pipe.—In place of the auger a pipe, provided at the end with sharp teeth, may be used, which is forced down into the soft material by twisting a two-foot handle. The sample will be a plug filling the pipe, representing the section of the length of the pipe. Another contrivance is a pipe with sharpened edges at the end, which is driven into the ground. In both samplers the plug of the material is, of course, forced out, another section of pipe connected with the first pipe and again started down. Both of them can be used more effectively in connection with a churn drill, which is able to cut through any hard material that may be met.

Whenever the material is very soft, as is the case with marl and marl clays, quite a number of devices are being used for doing this work and the most of them can be made by any mechanic without much trouble.

Hunt Sampler.—One sampler* offered on the market is that manufactured by Robert G. Hunt & Co., Chicago, Ill. It is a piece of steel tube about 18 inches long, slit longitudinally. The end entering the marl is capped and pointed with steel so that it will penetrate more easily. To the other end there is attached a longer or shorter rod, which can be turned by means of a handle. The two edges running lengthwise are sharp, so as to cut the marl. When the tool has been forced down to the depth desired it is turned half around, filling it with a clean swath of marl its whole length. Thus a perfect sample of the marl throughout the length of the sampler is obtained.

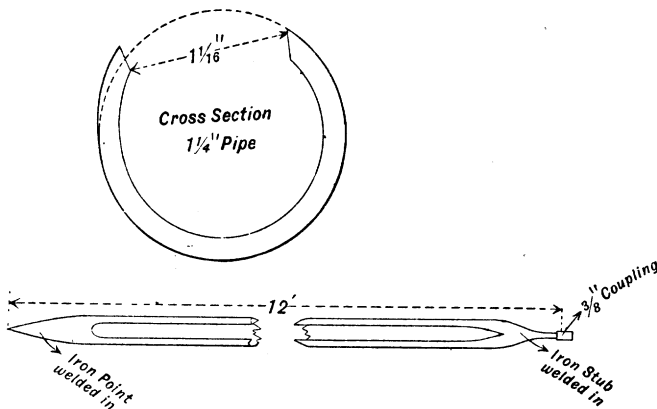


Fig. 9. The Hunt sampler.

Liquid Marl Sampler.—For marls almost in the liquid state the Geological Survey of Michigan used a modification of the Farr marl sampler.

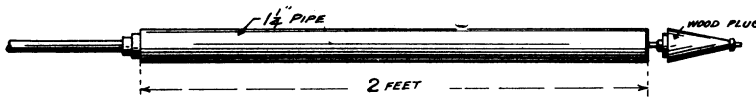


Fig. 10. The Farr liquid marl sampler.

The construction of this tool is readily understood from the diagram and it is used as follows:

The plug is first held firmly against the mouth of the pipe by means of the rod and the whole tool shoved down the desired length. Now the pipe is raised, holding the rod stationary, and is then shoved down to its former level, being forced tight against the shoulder of the plug. Both are now raised to the surface, the rod and plug removed and the sample taken from the pipe. A good sample can in this way be taken down to a depth of 18 feet. In order to cause the pipe to be forced down with greater ease it is best to sharpen the bottom edge.

*Geological Survey of Michigan, Vol. VIII, Part III, page 12.

Marl and Its Application to the Manufacture of Portland Cement, D. J. Hale and Others.

SAMPLING LIMESTONE AND CEMENT ROCK.

In working with these harder rocks the churn drill is indispensable, it being worked either by hand or by power. In every case it will pay to obtain the service of a professional driller, such as are found in every district. At a comparatively small depth, drill holes are rapidly put through limestone material with a power drill.

If the rock to be sampled is in a quarry or other exposure, a vertical channel should be cut into the face, from top to bottom, sufficiently deep to remove all weathered rock, so that the sample obtained may be a true one. By drilling and the proper use of explosives such work can be carried on quite rapidly, but should in every case be done under the guidance of an experienced quarryman. For rapid work the diamond drill has given very good results.

In preparing samples for analytical work it goes without saying that great pains must be taken in order that they be average samples. Unless care is taken to do this, the entire work is of little or no value. The original sample should always be as large as possible and the entire quantity should be crushed together to 8 mesh and then intimately mixed and quartered down to about ten pounds. This should be again ground so that it will pass a 20 mesh sieve, and again quartered down until the amount for a laboratory test has been obtained, about 500 grams, which must then be put through a 100 mesh sieve. One cannot be too careful or painstaking in this preliminary work, as its thoroughness governs the value of all subsequent work.

The Ohio Geological Survey carried on the sampling as follows:

The samples came from the field in sacks, provided with pasteboard tags on the outside and wooden tags on the inside of each sack, the weight varying from 50 to 150 pounds. Wherever necessary the sample was dried on a hot plate dryer and then crushed by means of a small jaw crusher; usually the entire sample was run through in this manner, if the sample was a large one. The material was now thoroughly mixed, it being fine enough to pass through an 8 mesh screen. If the sample was less than 45 pounds, all of it was put into a specially designed dry ball-mill and of course in this case it was not necessary to mix it before putting in the mill. This machine, made of chilled cast iron, proved extremely valuable in this work, since it not only ground the 8 mesh material to any desired fineness, but at the same time it produced a sample almost ideal as to uniformity. The grinding was done by Greenland pebbles, which, of course, introduced some silica, but so small in amount that it could be safely neglected. In another part of this report the machine is described in detail. The usual charge of the mill was from 40 to 45 pounds. When a charge was ground the lid of the machine was removed and the flint balls, together with the ground material, dumped into a long box placed beneath the mill. From this box the whole charge was

shoveled onto a heavy screen consisting of iron rods, forming about an inch mesh. This screen, about 3 feet by 3 feet in size, was placed within a box 15 inches deep and 3 feet square on the inside, and it was let down into the box about 5 inches, so there was a space of about 10 inches depth beneath the screen. A smaller flat box was placed within the large box, under the screen, before the mill charge was shovelled onto the grating. The latter was just close enough to keep back the flint pebbles, while the ground material dropped into the box below. This was found to work very well, and it was a simple matter to prepare batches of limestone samples, or clay, or experimental cement mixtures. Clinker also was ground on this mill. In grinding clays or shales these must be thoroughly dry or the material will stick to the pebbles. In some cases it may even be necessary to apply a gas flame to the outside shell of the mill while it is running, to prevent the "pasteing" of the charge. The mill makes about 27 revolutions per minute and the power required to run it is quite trifling.

The samples thus obtained are thoroughly homogeneous and any portion of the ground mixture is a true average.

Though every laboratory is not in possession of such an outfit, similar mills, though small, may be constructed or bought with comparatively little expense. A small porcelain lined ball-mill driven by an electric or water motor will be found a valuable accessory of every technical laboratory.

CHEMICAL EXAMINATION OF CEMENT MATERIALS.

The chemical examination of the various substances entering into the domain of cement manufacture will be considered under the following topics:

1. Natural pozzuolane materials.
2. Slags, total analysis and sulphur determinations.
3. Natural cements.
4. Clay analysis.
5. Mineral analysis of clay, by the sulphuric acid method.
6. Mineral analysis of clay by heating with calcium carbonate.
7. Standard methods of limestone and cement analysis.
8. Commercial methods of cement material analysis.
9. Determination of insoluble residue in raw mixtures and Portland cements.
10. Physical supplementary methods.
11. Carbon determination and coal analysis.
12. Mechanical analysis of raw mixtures, clays and cements.
13. Special problems in cement chemistry.

CHEMICAL EXAMINATION OF POZZUOLANE MATERIALS.

Technical examination of natural pozzuolane, trass and similar hydrous materials.

1. From what we know of pozzuolane materials we realize that their hydraulic value depends on the amount of available silica present, that is, silica soluble partly in hot hydrochloric acid and completely soluble in a hot solution of sodium carbonate. A complete analysis is required in but few cases, and is of little value except where some irregular constituents are making their influence felt.

The complete analysis of a pozzuolane is carried on, as is customary for silicates, by fusion with sodium carbonate, separating the silica, alumina, iron, calcium oxide and magnesium oxide as is done for clays, the method of analysis of which will be given later on under the proper heading.

2. The soluble silica is determined as follows. Treat one gram of the sample with 40 cc. of hot dilute hydrochloric (1:2) acid in a casserole, boil for five minutes, dilute to 150 cc. with boiling distilled water and keep boiling for 15 minutes. Now filter the liquid off through a hardened filter, wash several times with hot water, and rinse any residue which got on the filter back into the casserole. To the residue now add 50 cc. of a solution containing 1 gram of caustic soda and 3 grams of sodium carbonate. Heat on a hot plate or water bath, for 60 minutes, but do not boil. Filter through the same hardened filter as before and return any residue transferred to the filter to the casserole. Add now 50 cc. of the alkaline solution, of half the strength given above, and heat for 30 minutes. Filter as before and repeat this treatment at least twice more, till no more flocculent silicic acid is detected in the filtrate on testing with ammonium chloride. Sometimes the test is rather slow to show. In this case make decidedly acid with hydrochloric acid and add in the test tube a few drops of ethyl alcohol. Cooling the hot test solution rapidly in water accelerates the reaction. To the residue in the casserole add 10 cc. of the hydrochloric acid, dilute to about 50 cc., heat to boiling, filter and wash almost free from chlorine with water containing about 10 per cent. of ammonium nitrate and a little alcohol. The total filtrate is now made distinctly acid with hydrochloric acid and evaporated to dryness in a porcelain or, preferably, a platinum dish. The residue is now heated in a hot air oven, best lined with clay tiles, at 120° C., till fumes of hydrochloric acid are no longer detected. Take up in a little hydrochloric acid, add boiling hot water and filter on an ashless filter. The filtrate is returned to the dish in which evaporation took place and is again boiled down to dryness and heated at 120° C., say for one hour. Take up again in acid and hot water, filter on same filter and wash practically free from chlorine. Ignite and weigh as silica, SiO_2 . Final ignition must take place over a blast lamp. It is also advisable to test the purity of the silica with hydrofluoric acid.

The loss on ignition often is a valuable and sufficient criterion of the value of a pozzuolane material, it being due to the expulsion of the com-

bined water of the silicic acid. This simple method, of course, is applicable only to materials whose general composition is already known and can never be used as the sole method of comparing pozzuolanes.

ANALYSIS OF FURNACE SLAGS.

This method is quoted chiefly from "Notes on Metallurgical Analysis," by Professor N. W. Lord, professor of metallurgy and mineralogy at the Ohio State University and consulting chemist of the Ohio Geological Survey.

Weigh out one gram of the sample in a casserole, add 30 cc. of water and stir the slag to prevent caking. Now add 20 cc. of hydrochloric acid and heat. Everything should dissolve except a few flakes of silica and possibly a little carbon and sulphur. Evaporate to dryness and heat in the oven to a temperature between 110 and 120° C. till all of the acid is expelled. Take up residue in water and hydrochloric acid, filter off and transfer filtrate back to casserole for a second evaporation and heating. Take up in acid again as before, filter and wash. Ignite and weigh as silica. This residue is liable to contain traces of iron, titanium and spinel. It may be tested with hydrofluoric acid and any fixed residue deducted.

The alumina is now determined in the filtrate from the silica, to which a few drops of nitric acid have been added. In the absence of much manganese this can be done by precipitation with ammonium hydroxide, taking care to have plenty of ammonium chloride present and to redissolve the first precipitate, which is likely to contain a little lime. The precipitate is washed free from chlorine and then transferred to the filter. It may contain iron, phosphoric and titanitic acid in the slag, but as these are rarely present in noticeable quantities they may be neglected. If the slag contains much manganese the alumina must be separated from it by a basic acetate precipitation. The precipitate is then redissolved in hydrochloric acid and the alumina now free from manganese is precipitated by ammonium hydroxide. This, however, is rarely necessary.

The presence of much manganese also influences the determination of calcium. If, hence, more than a few tenths per cent. of manganese is present add 2 or 3 cc. of ammonium sulphide to the filtrate from the alumina. Heat to boiling and boil for three minutes. Cool the liquid and transfer to a 500 cc. graduated flask; 250 cc. of this volume can now be measured out by filtering through a dry filter into 250 cc. graduated flask. In this solution, representing half of the sample, the calcium and magnesium can be determined gravimetrically or volumetrically.

If ammonium sulphide was used, add HCl to the filtered solution till neutral and then about 5 cc. in excess. Boil till the hydrogen sulphide is expelled, then add 0.5 gram of potassium chlorate and heat till the separated sulphur is dissolved. Now add ammonium hydroxide and pro-

ceed with the determination of the lime. Should a trace of manganese dioxide separate on adding the ammonium hydroxide, continue the heating till it dissolves and the solution is nearly colorless before precipitating the lime.

Determination of Sulphur in Slag.—The sulphur in slag is usually present as calcium sulphide. For the purpose of determination the sulphur may be brought to the condition of the sulphate in two ways, the dry or the wet method. The former is accomplished by careful fusion with alkaline carbonate, the latter by treatment with acid and oxidizing agents like bromine or chlorine.

Fusion Method.—Mix 1 gram of the finely pulverized slag with 6 grams of sodium carbonate and 0.5 to 1 gram of sodium nitrate, according to the amount of sulphur expected. Put the mixture in a platinum crucible. Put a heavy layer of sodium carbonate on top of the mixture and fuse carefully. As soon as it is well melted, chill the crucible by dipping the bottom into water. This will loosen the cake so that it can be removed.

The fusion must be made over an alcohol or gasoline lamp. Boil out the fusion in the water till all the material is soft and no hard lumps remain. If the solution is colored by $\text{Na}_2\text{Mn}_2\text{O}_8$ add a few drops of alcohol. Filter and wash well with hot water. Add HCl to the filtrate till just acid, evaporate it to dryness carefully and dry at 100°C . Now add 5 cc. of hydrochloric acid first diluted with its own volume of water. Warm and add 50 cc. of water, heating till everything is dissolved but a little SiO_2 . Filter and wash. The filtrate should not exceed 100 cc. If it does, concentrate it. Now heat nearly to boiling and add 5 to 10 cc. of a 10 per cent. solution of barium chloride, previously diluted with 10 to 20 cc. of water and heated. Stir and let the precipitate of barium sulphate settle; when clear, filter, wash with hot water, ignite over Bunsen burner, cool, add one or two drops of sulphuric acid, ignite again and weigh the BaSO_4 . Calculate the sulphur.

Wet Oxidation.—Place sample of 1 gram into a hard glass bulb provided with a three-hole rubber stopper. In one hole there is inserted a separatory funnel, through the second a tube connected to a Winkler absorption coil containing bromine, while through the third connection is made with an air supply tank, containing air under low pressure.

Bromine water is poured over the sample in bulb and hydrochloric acid is added slowly at intervals through the separatory funnel. The hydrogen sulphide evolved is oxidized largely by the bromine in the bulb, and any gas escaping is taken care of by the bromine water in the coil. During the reaction the bulb is shaken occasionally. When the decomposition is finished, heat to boiling and allow to cool slowly. The contents of the bulb and coil are now united, the excess of bromine is

driven off and the residue filtered off. The sulphuric acid is precipitated by means of barium chloride as given in the fusion method.

Volumetric Methods—In addition to the method of determining the sulphur as barium sulphate, we have several methods of determining the sulphur from *sulphides* volumetrically. The best known of these methods employs a standard iodine solution using starch as an indicator. It is extremely useful in the examination of blast furnace slags and is very rapid. (See N. W. Lord, "Notes on Metallurgical Analysis," p. 102.)

THE EXAMINATION OF NATURAL CEMENTS.

The analytical methods employed in the analysis of natural cements are practically the same as those used in analyzing limestones with the exception that fusion must be resorted to in order to bring about complete solution of the sample.

Weigh out one gram of the finely ground sample and mix intimately on glazed paper with 3 grams of sodium carbonate. Transfer to a platinum crucible and raise slowly to a red heat over a Bunsen flame and after ten minutes, heat over the blast lamp for five minutes. Place crucible in casserole containing about 150 cc. of water, boil till mass has softened and has left the crucible, replenishing the water evaporated. Add hydrochloric acid till distinctly acid, keeping casserole covered with watch glass. Now add a few drops of nitric acid to solution and evaporate to dryness. The residue is heated at about 110° C. in a tile lined oven for one hour. After cooling, add 10 cc. of hydrochloric acid, let stand for a few minutes and dilute with boiling water. Filter and transfer filtrate back into casserole, evaporate to dryness as before and heat at 110° C. till all hydrochloric acid has been expelled. Take up again with 10 cc. hydrochloric acid, dilute with boiling water and filter through the filter used in the first separation of silica, thus adding any silica not separated in the first evaporation. In rapid technical work only one evaporation is made, but this never removes all of the silica present.

Now bring the filtrate to boiling and add ammonia to slight excess; boil for a few minutes and filter, washing several times with hot water. Remove funnel from above the filtrate and wash the precipitate of aluminum and ferric hydroxide into a clean beaker with hot water. Follow this by washing the filter with hot water containing 20 per cent. hydrochloric acid, allowing solution to run into the second beaker. Heat filtrate and precipitate in the fresh beaker till all of the iron and alumina is dissolved. Dilute, make slightly ammoniacal to reprecipitate the iron and alumina, boil for a minute and allow to settle. Decant clear liquid through the filter used before, taking care to wash it first with water containing a little ammonia.

The filter should be a 11 cm. ashless filter. Wash twice by decantation in this manner, using boiling hot water. If the precipitate is very

bulky, decant three times. Then transfer to the filter, wash, ignite and weigh as alumina and ferric oxide.

If it is desired to determine the ferric oxide in the material the quickest way of determining it is carried out as follows: Take two grams fuse with 6 grams of sodium carbonate and separate the silica as given above. After removal of the silica transfer the filtrate, acid with hydrochloric acid, to a 500 cc. flask and divide it into two portions, one of them being retained for the determination of the alumina and ferric oxide together, and of the calcium and magnesia; in the other half the iron is determined volumetrically by the bichromate method.

This is much more rapid than the solution of the ignited oxides of alumina and iron in potassium d.sulphate or sulphuric acid and titration with potassium permanganate. Of course for quick work, one gram may be used and this divided into two portions.

Heat the filtrate from the alumina and iron to boiling and add excess of a hot saturated solution of ammonium oxalate. Stir and allow to stand for five minutes. Filter off the supernatant clear liquid, and add boiling water to the precipitate remaining in the first beaker together with sufficient hydrochloric acid to redissolve the calcium oxalate. Raise again to boiling, add a little ammonium oxalate and make ammoniacal. Now allow the precipitated calcium oxalate to stand for one hour, filter and wash it, the filtrate being allowed to run into a fresh beaker. If in the first filtrate any precipitate is formed meanwhile, it must be filtered through the paper before the main precipitate is transferred.

The chief consideration in the calcium determination is that the work must be carried on as hot as possible, the solution and wash water being boiling hot. For very accurate work, the solution should stand for 12 hours in order to bring about complete precipitation of the lime. In rapid technical work, not more than ten minutes is allowed for standing, usually five. The difference between the five minute and 12-hours standing may be $\frac{1}{2}$ per cent. If the work is done with boiling solutions the deficit is considerably less than this. In rapid work with rock low in magnesia, the re-solution and precipitation is not necessary, but cannot be avoided in the case of magnesian stone.

Ignite the precipitate of calcium oxalate over the blast lamp, cool, and add enough nitric acid to dissolve the oxide. Now add five or six drops of sulphuric acid and take the mass to dryness by heating gently with a Bunsen flame till the white fumes of sulphuric acid have ceased coming off. If no sulphuric acid fumes are seen, add more sulphuric acid and reheat. Then bring the residue to a dark red heat over the Bunsen flame and weigh it as calcium sulphate.

With a good blast lamp it is possible to ignite the calcium oxalate to the oxide and to weigh as such. In technical control work, the calcium is determined with sufficient accuracy volumetrically as described under the head of the examination of calcareous Portland cement material.

In the united filtrate from the calcium the magnesium is determined. Add to the cold liquid, 25 cc. of saturated solution of sodium diphosphate and excess of ammonia. The amount of solution should not exceed 400 cc. Stir thoroughly and let stand for 12 hours, especially when much magnesia oxide is present. Filter and wash with water containing about 10 per cent. of its volume of ammonia and some ammonium nitrate, about 100 grams to the liter. Dry and ignite the precipitate, which is magnesium pyrophosphate.

In examining natural cements it is sometimes necessary to determine the carbonates still present after burning, so as to obtain a numerical expression for the completeness of the burning. This is done by expelling the carbon dioxide with hydrochloric acid and absorbing the gas as usual in potash bulbs.

It may be desirable to make the determination of unburnt carbon in a natural cement. This is carried out with a sample treated with hydrochloric acid in order to decompose any carbonates present. After the acid treatment and expulsion of the free acid the sample is burnt in regular combustion tube, or a Shimer crucible, the carbon dioxide being absorbed in potash bulbs.

For rough approximation of the amount of water of hydration, carbon dioxide and carbon present in natural cements simple heating over the blast lamp will usually suffice.

COMPLETE ANALYSIS OF CLAY.

Fuse $1\frac{1}{2}$ grams of the clay with 10 grams of sodium carbonate and separate the silica by double evaporation as given under the examination of natural cement. Test the weighed precipitate with hydrofluoric acid and any residue remaining, usually very small, should be considered as alumina. It is absolutely necessary to carry out the double evaporation, as without it no satisfactory results can be obtained. Filter the silica through a 11 cm. ashless filter. The evaporation should be done on a hot plate or asbestos stove. Frequent stirring during the pasty stage of evaporation is necessary.

The amount of silica obtained multiplied by 0.666 will give the silica in one gram.

Now transfer the filtrate from the silica determination to a flask calibrated to hold 600 cc. Retain of this volume 400 cc. for the determination of alumina and ferric oxide, lime and magnesia, and remove 200 cc. for the determination of iron by the bichromate method. The amount of iron found is of course multiplied by 2 to obtain the ferric oxide in one gram of sample. This procedure is much more rapid than the determination of iron by the permanganate method. If the latter is used, precipitate with ammonium hydroxide, the alumina and iron in the portion of 200 cc. which has been removed, decant the supernatant liquid and transfer the precipitate to the filter and wash it

with hot water. Now wash the hydroxides from the filter into a clean beaker and dissolve in dilute sulphuric acid. In the presence of titanium, reduce the iron with hydrogen sulphide, which must be expelled by boiling and by passing carbon dioxide through the liquid. Now titrate the solution of ferrous sulphate with potassium permanganate as usual. The use of hydrogen sulphide is especially necessary in the analysis of fire clays, where titanium oxide is never lacking and the iron content is very low, while for brick clays it is of little importance whether this is done or not. The bulky colloidal precipitate of aluminum and ferric hydroxide can only be washed sufficiently by decantation and water. This is provided for by arranging a large can, made of tin-lined copper, holding from 5 to 10 liters of water, at a considerable height above the laboratory table. This is kept gently boiling all the time and is supplied to the beakers or funnels by means of a long rubber tube provided at the end with a glass tube drawn out to a point and a pinch cock. This should be long enough to be swung from one end of the table to the other so that it may also be used for washing precipitates in place of the wash bottle. The tube can be counterbalanced by means of a weight running over a pulley.

The liquid to be decanted is best syphoned into an evaporating dish and kept boiling so that the volume may be reduced as quickly as possible to the desired volume. It is necessary to filter the concentrated washings in order to recover any small amounts of alumina and iron carried over.

In this as well as other industrial chemical work it is of extreme importance to watch closely the quality of the reagents used. It is best to frequently run blank determinations on each process so as to ascertain the exact amount of the impurities being brought in by the reagents used.

PROXIMATE OR MINERAL ANALYSIS OF CLAY

Repeated attention has been called to the mineral composition of clay, to its principal mineral constituents, clay substance, feldspar and quartz. The actual determination of these three constituents, according to Seger and Bischof, is carried out as follows:

Take one gram of the clay, transfer it to a casserole and add 50 cc. of sulphuric acid. Heat till white fumes begin to be given off and continue the heating for 8 hours. The volume must be kept up by the occasional addition of more sulphuric acid. After this heating cool the liquid and dilute with water to about 250 cc. Heat the diluted solution, and filter through a hardened filter and wash the precipitate, which has been transferred to the latter, with a hot solution of dilute hydrochloric acid (1:5) followed by washing with hot distilled water. Now carefully wash the precipitate back to the casserole and add 50 cc. of a solution containing 3 grams of sodium carbonate and $\frac{1}{2}$ gram of caustic soda. Heat almost to boiling for 30 minutes, and decant through the same hardened filter. Wash any precipitate on filter back into casserole, into which pour 50 cc. of a solution

containing 3 grams of sodium carbonate and 0.1 gram of caustic soda. After heating the liquid, decant again through the same filter. Repeat until no more silicic acid is found in the filtrate. Usually four washings are sufficient. Then transfer the residue to the filter which has done service throughout this analysis and wash with hot water, acidulated with hydrochloric acid. Finally finish the washing with a 10 per cent. solution of ammonium nitrate. If the filtrate should become turbid, the addition of a little ethyl alcohol usually prevents the running through of the fine matter of the residue. Ignite and weigh the insoluble residue.

Mix the insoluble residue with eight times its weight of sodium carbonate, fuse and determine the silica as usual. In the filtrate from the silica precipitate the iron and alumina and weigh as in the regular analysis.

We can now calculate the amounts of clay substance, quartz and feldspar as follows: One gram minus the weight of the insoluble residue multiplied by 100 gives the per cent. of clay substance and all other minerals soluble in boiling sulphuric acid, like mica, hornblende, carbonates of iron or calcium, etc. The per cent. of silica in the insoluble residue minus 3.52 times the weight of the alumina and ferric oxide in the insoluble matter multiplied by 100 will give the per cent. of quartz, while the weight of the insoluble residue minus the weight of the quartz as just calculated times 100 will give the per cent. of feldspathic matter. The constant 3.52 is obtained from the typical analysis of orthoclase feldspar and is equal to the ratio between the per cent. of silica and the per cent. of alumina, which are 64.76 and 18.4, respectively.

This method of analysis can make no claim to scientific exactness, but gives a close approximation to the actual mineral composition of white burning or kaolin-like clays. It does not give equally exact ideas, as to the constitution of the impure red-burning clays and shales, chiefly because the minerals taken into solution by sulphuric acid are numerous and the matter thus classified as clay substance, bears little resemblance to the constitution of real kaolinite.

This method, though giving extremely valuable data in regard to the mineralogical character of a clay, yet neglects to give expression to the coarseness or fineness of the grains composing the matter insoluble in acid, and hence fails to indicate the readiness with which the clay unites with lime to form silicates and aluminates. In order to overcome this to a certain extent, a mechanical analysis would have to be made of the insoluble residue, which, however, would still fail to tell just which of the various sizes are feldspar and which quartz. Lime can decompose and unite with the constituents of feldspar, the latter being a silicate, with far greater ease than with quartz, both being assumed to have the same size of grain. Hence we see that the ordinary rational analysis is deficient and does not produce exactly the kind of data desired.

MINERAL ANALYSIS OF CLAY BY HEATING WITH CALCIUM CARBONATE,

Lunge and Schochor proceed on an entirely different basis and make use of the fact, more akin to the purpose in view, that silicates are unlocked by being heated in contact with CaO , as is clearly shown by the J. Lawrence Smith method of alkali determination. These investigators, though they did not work with clays proper, but with marls, succeeded in showing that the CaO attacks most readily the combined silica and the silica present in a fine state of division, thus giving a direct expression of the cement-making value of the materials. By heating sufficiently, treating with hydrochloric acid and sodium carbonate the unlocked bases and the soluble silicic acid are removed, and the residue remaining is simply the matter which was not rendered soluble by the action of the CaO during the heating process.

The work by Messrs. Lunge and Schochor in regard to this investigation was very extensive, and before adopting their final method they made very thorough preliminary tests. The results obtained by them may be summed up as follows:

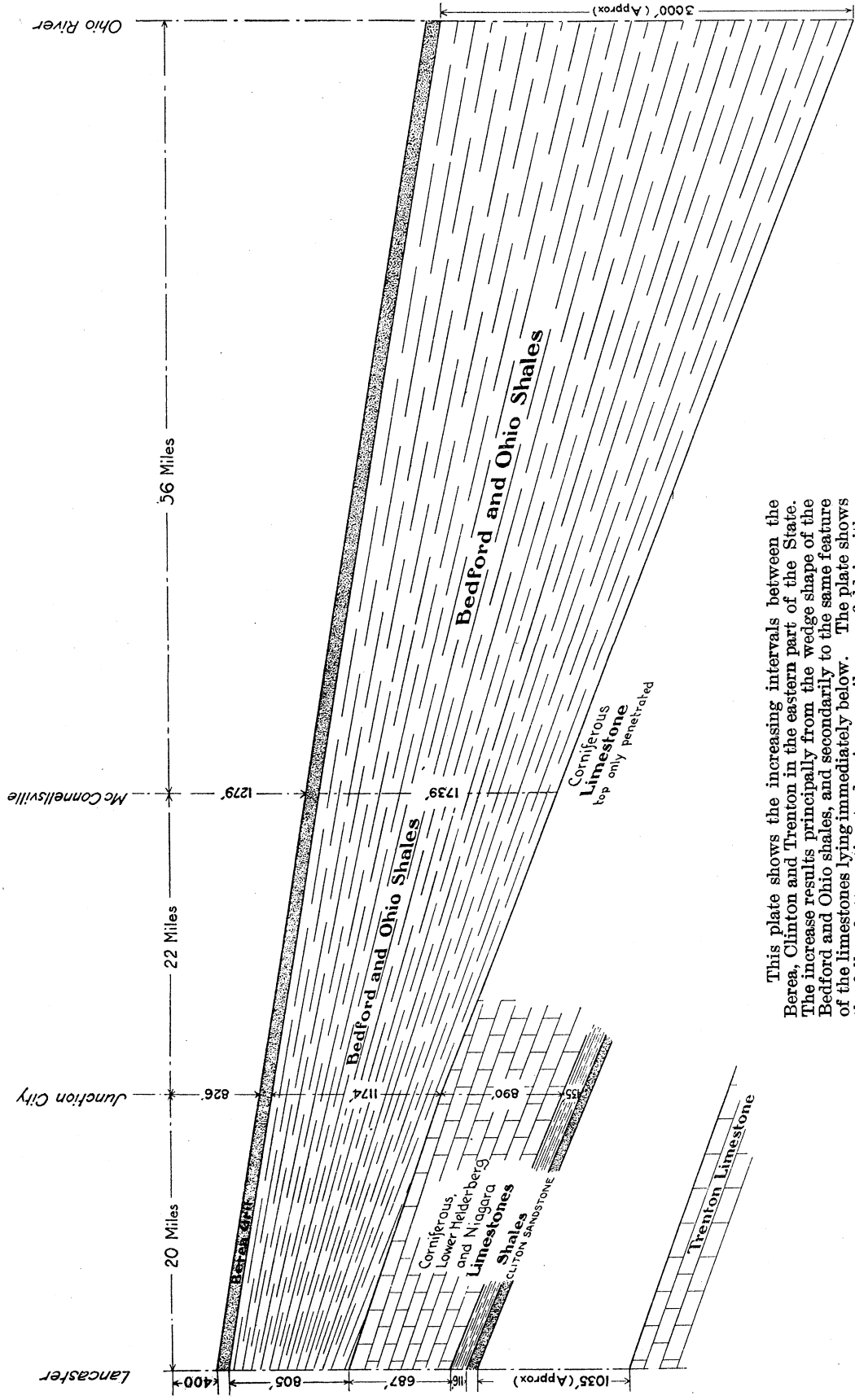
1. The solubility of raw marls in acid is not a sufficient criterion for determining their hydraulic value because acids are not proper reagents for determining unlocked silica, since silicic acid itself is soluble in acid only in proportion to the amount of chemical water contained by it. The acid treatment does not discriminate between coarse and fine silica, between amorphous silica and crystalline silica, nor between feldspar and silica.

2. However amorphous silica and quartz may differ otherwise, they show but little variation in behavior on burning with lime. The fineness of grinding is far more important. Although with the same degree of fineness and the same mode of mixing with equal amounts of CaO and heating under similar conditions, amorphous silica gives rise to a higher percentage of soluble silica than the quartz or a mixture of the two kinds of acid, yet when ground sufficiently fine, even pure quartz is acted upon almost completely and much more so than amorphous silica not so fine, but still extremely fine from the ordinary standpoint. Since the activity of silicic acid depends upon its contents of chemical water, after ignition it does not differ from so much quartz.

3. Chemically combined silica is completely unlocked. No matter how fine free silica is, it is always attacked less than silica in combination and hence it is shown that the best source of silica for cement purposes is a silicate, as far as transportation of the silica to the lime is concerned.

Lunge and Schochor have thus indicated a way by means of which it is possible to determine the per cent. of chemically active material in a marl, to separate the combined and very fine silica from the coarser quartz, thus permitting the statement that the higher the per cent. of silicate and very fine quartz is in a clay the higher is the value of the latter for hydraulic purposes. In other words, the higher the per cent. of dissolved

SECTION FROM LANCASTER DUE EAST TO OHIO RIVER



This plate shows the increasing intervals between the Berea, Clinton and Trenton in the eastern part of the State. The increase results principally from the wedge shape of the Bedford and Ohio shales, and secondarily to the same feature of the limestones lying immediately below. The plate shows the folly of attempting to develop an oil or gas field in either the Clinton or Trenton in the eastern part of the State.

material after heating with CaO and treating with HCl and Na_2CO_3 the higher is the value of the clay for hydraulic cements.

The method of working adopted by the two investigators named was as follows:

Samples of marl were taken, in the shape of lumps of walnut size which were heated in a gas furnace to a temperature of about 1100°C . without pulverizing or mixing, for two hours. These burned samples were pulverized, treated with HCl and Na_2CO_3 the residue being weighed after thorough washing. The value of the respective marls was expressed inversely by the per cent. of residue.

In order to prove that these tests really stand for expressions of the hydraulic value of the marls, Lunge and Schochor proceeded to grind the materials and to make cements of them by burning to vitrification and grinding the resulting clinker. The burning was done in a small test kiln. The hydraulic cements thus produced were subjected to the usual cement tests, which proved strikingly that for the marls examined, the hydraulic value was a function of the solubility of the clayey constituents when treated as mentioned above.

Upon studying the results obtained by Lunge and Schochor, Prof. Edward Orton, Jr., suggested the use of this method for the testing of clays in regard to their suitability for cement manufacture. The investigators just named restricted their method to marls, and although it is extremely valuable for the determination of the hydraulic value of any one marl, yet its results are not generally applicable and must always be restricted to this class of material. The factors in this method are evidently the variables of the clay substance, coarse and fine quartz, coarse and fine feldspathic matter, and in addition to this the lime contents. This evidently may in some cases give rise to conflicting results, as for instance, when there are two marls to be examined of which one has a coarser grain of sand, but a higher content of lime than the second marl, which is fine grained and has a higher percentage of combined silica but a lower per cent. of lime. The method now suggested for clays adopts a constant amount of lime, thus eliminating one variable.

The identity of structure which Lunge and Schochor are so careful to preserve by burning the materials in lumps is not interfered with by reducing them, *without grinding*, to the size of a 40 mesh sieve. In fact by burning the materials in lumps the outside factor of irregularity due to natural formation is so great as to introduce an additional source of error. For a product as homogeneous as cement the consideration of the bed structure is entirely unnecessary.

Thus the process of the Ohio Geological Survey is intended to determine the hydraulic factor of a clay by reducing the latter without grinding, with the assistance of water, so that it will pass through a 40 mesh sieve, care being taken not to reject the coarser material left on the sieve nor to break up any particles by grinding. When in the state

of a slurry, lime is added in the shape of precipitated calcium carbonate and thoroughly stirred with the clay. This mass is now dried down and rubbed through a 40 mesh sieve, mixed thoroughly on a sheet of glazed paper by means of spatula and burned in a furnace. A weighed amount of the ignited mixture is treated with hot hydrochloric acid for five hours, filtered and washed, and the residue is digested with a 10 per cent. solution of sodium carbonate with heating, until no more flocculent silica is observed on testing with ammonium chloride.

The Lunge and Schochor method and that of the Ohio Geological Survey differ in the following respects:

1. The above named investigators restrict their method to marls, while the Survey extends it to the testing of all clays.
2. The former work with the natural materials, having varying percentages of lime, while the latter maintains a constant amount of lime by adding the lime lacking, in the form of pure calcium carbonate and also having the lime present in excess.
3. Lunge and Schochor ignite the materials in the shape of lumps taken from the deposit; the Survey reduces them so that the soft portion will pass through a 40 mesh sieve with the aid of water and accomplishing the mixture of clay and lime when the former is in the condition of a slurry.

Experimental Work in Demonstration of the Value of the Process.—

Having thus outlined the method of working, there now remains to prove that it really gives expression to a co-efficient which is consistent with actual results in the manufacture of cement. For this purpose it was decided to bring the method as nearly possible to uniform conditions of operation and to agree upon a method of mixing, burning and analysis.

The description of the work done naturally falls under the following headings:

1. Sampling and preparation.
2. Mixing.
3. Burning.

Sampling and Preparation.—The clays arrived at the laboratory of the Ohio State University Ceramic Department in sacks, in the shape in which they were sent by the field collector. These clays, according to their nature, were treated in different ways. Clays of the soft, alluvial type, after being put through an 8 mesh sieve and repeatedly quartered according to the quantity on hand, were dried at 100° C., and about 500 g. was reserved for the analysis, being run, as far as possible, through a 40 mesh sieve and thoroughly mixed; the coarser portion, of course, being added to the finer. When the material was a hard shale, it was necessary to crush it and pass it through an 8 mesh sieve. A quantity of the reduced shale was then heated at 100° C. till perfectly dry and then allowed

to soak in water for 24 hours. If this was not sufficient, boiling was resorted to, which was kept up for 6 to 8 hours, if necessary. The mass was then evaporated to dryness and rubbed through a 40 mesh sieve. For very hard material, rubbing with a rubber pestle may be permitted.

Mixing.—The sample was now ready to be mixed with the lime. This was done by weighing out about 25 grams of the clay to be examined, whose gross analysis must be known, stirring it up with water to a thin slip and adding reprecipitated calcium carbonate. This mixture was stirred thoroughly, evaporated to dryness, rubbed through a 20 mesh sieve and thoroughly mixed with a spatula.

At this stage of the work it was necessary to determine the proper amount of lime to be added to a clay so as to attain the object sought, that is, the decomposition of the clay substance proper and the formation of a lime silicate, without running into danger of fusing the resulting mixture at the temperature employed in heating. In order to accomplish this a series of test-mixtures was made, employing a very fine-grained, soft clay, with little bonding power, which is used in the manufacture of Portland cement, at Harper, Ohio. The clay has the following analysis:

SiO ₂	50.70
Al ₂ O ₃ +Fe ₂ O ₃	17.00
CaCO ₃	16.80
MgCO ₃	9.80

The clay by itself was made the start of the series and the lime was increased as shown by the following table. The mixtures were burned at a temperature of 1100° C., this heat being maintained for 75 minutes. The mixtures of clay and calcium carbonate were made up into briquettes weighing about 75 grams, with the aid of water, placed upon a biscuit plate and burned in the small furnace used for this purpose.

No.	Per cent. of Calcium Carbonate.	Per cent. Residue.	Remarks.
1	16.8	....	Clay alone.
2	25.	....	
3	30.	....	
4	35.	....	More or less completely fused.
5	40.	....	
6	45.	....	
7	50.	....	
8	55.	....	Vitrified.
9	60.	3.55	Quite hard.
10	65.	....	Hard.
11	75.	1.12	Soft, but somewhat too hard for easy reduction.
12	80.	2.16	Soft.
13	85.	3.00	Soft and friable.

No. 11 of the table must be considered doubtful, an error having certainly been made in the analytical work. The results of the table show that

it is essential to have at least 75 per cent. of calcium carbonate present in the mixture, not so much because less lime might not unlock the silicate or not attack the free silica, but owing to the fact that the resulting mass after burning becomes hard and stone-like and hence inconvenient for reduction. For this reason it was decided to use a standard mixture of 80 per cent. CaCO_3 and 20 per cent. of the clay be tested, which results in a friable mass easily reduced. This amount of lime also allows for a sufficient excess, so that uniformity is obtained as far as the reagent is concerned.

In the determination of the insoluble residue of these mixtures sufficient material was taken to correspond to two grams of the clay. In this and other series the total lime was determined volumetrically in a number of analyses. This was done in order to express the per cent. of residue in terms of the actual weight of clay taken, thus making due allowance for the lime introduced as reagent, since the mixing of clay and lime can never be so intimate as to make it permissible to weigh out any amount of the mixture and obtain the actual amount of clay taken by calculation, depending upon the per cent. of calcium carbonate originally added under the supposition that the mixture is perfect. Later on this method was modified in such a way that 2 grams of the dried clay were weighed out, transferred to a beaker and made up into slip with water. To this was added the amount of lime corresponding to the required proportion of 1 part of clay to 4 of calcium carbonate. The mixture was carefully transferred to a porcelain crucible, evaporated to dryness, mixed on a sheet of glazed paper with the spatula and returned to the crucible in which the sample was burned, being covered with a lid. In this way, of course, the determination of limes becomes unnecessary.

The analysis proper is carried out by taking the sample, treating with hydrochloric acid (1:3), allowing it to boil for five minutes till in solution. This liquid is now filtered and washed nearly free from chlorine, the residue being washed back into the casserole and treated with the alkali solution as indicated under the head of rational clay analysis till no more silicic acid is found in filtrate. The residue is then treated with hydrochloric acid (1:4) washed free from chlorine, ignited and weighed.

The main precaution to be observed is to keep the work as hot as possible, while yet allowing the silicic acid to settle. The use of long stemmed funnels is to be preferred to suction flasks.

Burning.—For burning the mixture, there was available a dental furnace manufactured by the American Gas Furnace Co. which was intended to be fired with gasoline vapor, but which was modified so as to burn ordinary kerosene. For this purpose a $\frac{1}{4}$ inch pipe was introduced into the lower cylindrical part of the furnace. The pipe was run to a can fastened to the wall and was fed with oil from the reservoir by

means of a stop cock and funnel. The oil dripped into the open furnace making a sight feed arrangement. The blast was furnished by a positive rotary blower through a $\frac{3}{4}$ inch pipe.

The mode of operating the furnace was as follows: At the bottom of the cylinder beneath the furnace proper there was placed a small shallow iron pan into which the oil dripped from the feed pipe and which served as an evaporator for the oil. When ready for operation a small bunch of waste saturated with oil was placed upon the pan, ignited and covered with a few pieces of wood and charcoal. Upon this small charge of fuel there were now placed pieces of fire brick, the size of a large walnut, which filled up the cylinder completely and served the purpose of offering resistance to the passage of gases and air, thus mixing them for proper combustion. The air was blown in through three small tuyeres distributed around the cylinder. As soon as the charcoal was fully ignited, the kerosene was allowed to flow slowly and a weak blast maintained. Gradually the flow of oil and the blast were increased, until the maximum supply was reached.

Before the supply of oil had begun, a fire clay tile was placed across the furnace occupying the space formerly taken up by the muffle. Upon this tile were placed the crucibles or biscuit saucers carrying the samples to be ignited. At the same time a porcelain tube containing the platinum wire and thermo-couple of a Chatelier pyrometer was placed in position, just touching the mixtures to be heated.

The rise in temperature was readily followed by means of the pyrometer whose millivolt meter is set up in a closet at a distance of about 7 feet from the furnace.

The question now arose in regard to the temperature to be employed in the burning. It was at once evident that the work to be accomplished by the heat is two-fold.

First, the carbonic acid must be expelled from the calcium carbonate.

Second, the silicate must be decomposed and the finely divided silica converted into lime silicate, soluble in acid.

The first function obviously fixes the lowest limit of the temperature to be employed. From the work done by Prof. Hertzfeld, we know that at a temperature of 1050° C. the carbonic acid is completely expelled. Lunge and Schochor employed a temperature between 1060° and 1120° Centigrade, their statements being in this respect not as definite as could be desired. However, from the extensive knowledge in existence in regard to the unlocking of silicates by the J. Lawrence Smith process, we know that it is not necessary to carry the temperature very high and this is also not desirable owing to other considerations. The heating must not be carried so high that silicates and aluminates analogous to those of hydraulic cements are formed, reactions which are entirely uncalled for in this process, and which might result in the crystallization of compounds.

of different solubilities. We thus have the limits of temperature fixed, the lower one being that of the complete expulsion of carbonic acid and the higher one being that of the formation of hydraulic silicates and aluminates.

It was not thought necessary, in view of the knowledge available, to undertake an extended series of experiments as to the temperature required. But it was decided to heat a mixture of clay and carbonate of lime at different temperatures and to observe at what temperature the residue becomes constant. For this purpose a marl, from Harper, Ohio, was selected, whose composition is as follows:

	Per cents.
SiO ₂	8.75
Al ₂ O ₃ +Fe ₂ O ₃	2.78
CaCO ₃	79.22
MgCO ₃	2.67

A sample of this material was heated to 1000°, 1050°, 1100° and 1150° C. with the results as shown by the following figures, the time chosen being 90 minutes, that is, the respective temperature was maintained for this time. The amount of marl taken for analysis was 2 grams.

Temperature.....	1,000°	1,050°	1,100°	1,150°
Residue.....	2.06	1.00	0.4	.....

The results were found to check sufficiently close in other burns. The samples were made up into briquettes.

It is thus seen that practically all the marl was decomposed at 1100°. Although this series might have been extended to mixtures of clay and carbonate of lime, yet the fact that this marl, which is acknowledged to be a most excellent cement material, was practically decomposed, together with the data obtained from the work of Lunge and Schochor, Hertzfeld, Smith, seems sufficient to warrant the acceptance of this temperature as the standard.

The question of the time of heating was one that next needed attention. In order to determine the factor of time, the same marl was used and heated for 30, 60, 75, 90 and 120 minutes at the temperature of 1100° C. with the following results:

Time, minutes.....	30	60	75	90	120
Residue, per cents.....	8.6	1.28	0.4	1.0	0.55

In spite of the irregularity in the 90-minute burn, which shows an increase of 0.6 per cent. of the residue, it was decided to adopt 75 minutes as the standard length of the rational burn. The irregularity may be explained as one of the variations necessarily coincident with all rational analyses of this kind, which do not work upon finely pulverized, homogeneous samples.

By 75 minutes is meant the time during which the sample is exposed to the temperature of 1100°C ., which of course means a much longer burn, since one hour elapses before the furnace can be raised to 1100° .

There can be little doubt but that the time thus allowed is ample to accomplish the intended result. It is well known that for the complete decomposition of silicates in the alkali determination, a heating of 50 minutes over a Bunsen burner is sufficient, the temperature of which certainly does not exceed 1100° .

Having thus arrived at standard conditions of burning which, in the nature of the case, are bound to be more or less arbitrary, it was decided to apply this method to typical constituents of clay, prepared in several well-graded sizes. For, by knowing the action of lime upon each of these materials and for each of the several sizes of grain, it is possible for us to obtain a more definite idea of the character of the more inert constituents of clay, not readily available for hydraulic purposes. Of course, we can say in general that as particles of quartz, feldspathic and micaceous minerals are coarser, the more resistant will they prove to the action of lime, yet we do not know just to what extent the chemical action of lime is affected by the size of grain.

For this reason two series of experiments were carried out in which quartz and feldspar grains were burned together with lime in a mixture containing 80 per cent. of the calcium carbonate, the heat being maintained for 75 minutes at a temperature of 1100°C .

The quartz taken for this purpose was pure quartzite which was crushed and graded to the sizes by sieving. Six sizes were adopted, as follows:

1. Grains between 150 and 120 mesh sieve.
2. Grains between 120 and 100 mesh sieve.
3. Grains between 100 and 80 mesh sieve.
4. Grains between 80 and 60 mesh sieve.
5. Grains between 60 and 40 mesh sieve.
6. Grains between 40 and 20 mesh sieve.

In addition to these sizes, there was included in the series a ground flint, as sold to potters, which is quartzite ground to a fine powder in ball-mills using flint pebbles.

After being mixed with CaCO_3 in the condition of a slip, the mixtures were evaporated to dryness and made into briquettes which were burned.

On making the rational analysis the results obtained were as shown in the following table:

Sizes.	Ground flint.	150-120	120-100	100-80	80-60	60-40	40-20
Per cent. residue.....	28.83	63.8	78.53	86.52	86.27	93.78	96.83
Per cent. taken in solution.....	71.17	36.2	21.47	13.48	13.73	6.22	3.17

This table shows quite strikingly the effect of size of grain upon the action of lime, and brings out two kinds of facts which have a direct bearing upon the cement industry.

It confirms the general statement that the coarser the grain, the smaller the effect of the lime. Free silica contained in clay, unless very fine, finer than that passing through a 150 mesh sieve, is rendered available only after thorough grinding, which means a certain extra amount of wear and tear of machinery, and a decrease in efficiency corresponding with the coarseness of the quartz.

The second fact is to a certain extent opposite in character to the first. It tells us that it is commercially possible to reduce free quartz to a fineness in which it is available for combination with lime. To be more clear, it may be said that of two clays available, one high in alumina and low in quartz, and one with a proper alumina content, but rather high in free silica, the results in regard to the quality of cement will certainly be better when the silicious material is used, in spite of the fact that its grinding is more difficult.

The tendency, only too common, is to work softer clays, which often bring in more alumina, and result in a tendency to "hot" cements, which must be toned down by gypsum. Granted that the presence of quartz makes it necessary to grind longer, yet the clay should not altogether be chosen with regard to its easy reduction, but also in regard to the ultimate quality of the cement.

Similarly to the quartz series, the same process was carried through with the corresponding sizes of feldspar grains, which were obtained from several fine specimens of orthoclase crystals, that apparently had not been kaolinized perceptibly.

Sizes.	Ground Feldspar.	150-120	120-100	100-80	80-60	60-40	40-20
Per cent. residue.....	3.75	15.45	31.00	64.29	79.63	95.72	.....
Per cent. taken in solution.....	96.25	84.55	69.00	35.71	20.37	4.28	.....

These results show at once the great difference between quartz and feldspar in regard to being acted upon by lime. It becomes evident that feldspar is a desirable constituent of cement materials. Light-burning clays high in feldspar should therefore receive more attention with reference to the manufacture of light-colored cement.

In addition to these series, commercial potter's kaolin of a good grade was treated by the same process, resulting in a residue of 3.07 per cent., 96.93 per cent. being taken into solution. This verifies the work of the German investigators, who found that clay substance was easily unlocked by lime.

Finally a synthetic mixture, having the following composition, was prepared with the intention of closely imitating such a clay as is commonly found in the alluvial or glacial clays of the country, and as is likely to be tried as a source of silica and alumina in cement manufacture.

	Per cent.
Commercial washed kaolin	50
Feldspar, 150-120 mesh.....	10
Feldspar, 120-100 mesh.....	10
Quartz, 150-120 mesh	10
Quartz, 100-80 mesh.....	10
[Quartz, 60-40 mesh.....	10
	100

This mixture would have on analysis a composition roughly as follows:

	Per cents.
SiO ₂	65.50
Al ₂ O ₃	24.00
K ₂ O.....	3.00
H ₂ O.....	7.50
	100.00

Upon being heated with lime it showed, on analysis, a residue of 31.36 per cent., 68.64 per cent. having been taken into solution. The residue, calculated from the previous experiments, should be 30.72 per cent., which is a practical check on the previous work.

The foregoing method has yet to be subjected to the wide test of practical application. Not until it is demonstrated that the clays which this method condemns, are also condemned after actual use as cement materials, and that clays which this method endorses as good, are actually found good in use, can it be treated as an established and valuable thing.

However, its claims to usefulness rest on broad and secure technical reasoning. No one can successfully dispute that clays, which give up their silica most readily to the action of lime, are, other things being equal, the best for making cements. Neither can any one affirm that any other method yet proposed or used, has been successful in showing any close relation between the amount of sandy minerals in a clay and its value to the cement-maker.

The clay must contain other sources of silica than that of kaolinite, if it is to be serviceable to the cement-maker, and, in addition, these sources must be such as will readily yield it up. The older methods have stopped after showing that the requisite silicate matter is present. This proposed method is designed to go one step farther, in showing not only

that it is present quantitatively, but also whether it is qualitatively suitable as well. It shows whether the silicate matter which is present, is in a form in which it will be readily assimilated into the calcium silicates to be formed, or whether it is in such physically unfit condition that only a limited part of it will be useful.

In the latter case, using the data furnished by the older methods, the cement-maker is likely to produce a cement too poor in combined silica. Or, if he recognizes this danger, and uses an excess of clay to bring the proportion of available silica up to the proper point, he runs into the counter difficulty of bringing in too much alumina.

This method of analysis enables us, therefore, to discriminate between clays as to their cement making value. An ideal clay when heated with calcium carbonate and treated with hydrochloric acid and sodium carbonate solution should show practically no insoluble residue, and as a rough approximation it might be said that no clay considered for cement making purposes should contain more than 10 per cent. insoluble residue. If, hence, a clay has the proper alumina-silica ratio and shows a small insoluble residue without extremely fine grinding it may be said to be entirely suitable for cement manufacture. Likewise, this method furnishes a most excellent guide as to the fine grinding of the raw materials, that is, how long a given mixture must be ground in order to show complete solution which is equivalent to perfect chemical activity. On the other hand it shows also when we are grinding a mixture too long, that is, when we are expending unnecessary power on this operation.

The heating of the clay-calcium carbonate mixture may be done over any good blast lamp.

ANALYSIS OF CALCAREOUS MATERIALS.

In this connection we must clearly distinguish between the accurate academic methods of analysis and the rapid methods practiced by the factory chemist which lack more or less in accuracy. Owing to the various modifications of methods employed in cement practice the results obtained by the various chemists must show considerable variation. The Society of Chemical Industry has endeavored to systematize analytical methods pertaining to the analysis of calcareous materials and its committee has proposed the following tentative method,* as suggested by Mr. Clifford Richardson and modified by Mr. W. F. Hillebrand for the analysis of limestones, raw cement mixtures and Portland cement:

EXACT METHODS.

Solution.—One-half gram of finely powdered substance is weighed out and, if a limestone or underburnt mixture, strongly ignited in a platinum crucible over the blast lamp for 15 minutes. It is then transferred

*Report of the Subcommittee on Uniformity in Analysis of Materials for the Portland Cement Industry. *Jour. Society Chemical Industry*, No. 1, 1902.

to an evaporating dish, preferably platinum, covered with a watch glass and 10 cc. hydrochloric acid diluted with about 50 cc. of water added. Digestion on the water bath is allowed to go on for about 15 minutes, when the substances should be entirely decomposed. The cover glass is then removed, washed and the solution evaporated to dryness on the water bath.

Silica.—The residue without further heating is treated at first with 5 to 10 cc. strong hydrochloric acid and then as much water as the dish will hold.

The cover is replaced and digestion allowed to go on for 10 minutes on the bath, after which the solution is filtered and the separated silica washed thoroughly with hot water. The filtrate is again evaporated to dryness, the residue without further heating taken up with acid and water and the small amount of silica it contains separated on another filter paper. The papers containing the residue are transferred to a weighed platinum crucible, dried, ignited first over a Bunsen until the carbon is completely consumed and finally over a blast for 30 minutes and checked by further blasting of 10 minutes or to constant weight. The silica, if great accuracy is desired, is treated in the crucible with about 10 cc. hydrofluoric acid and 4 drops of sulphuric acid and evaporated over a low flame to complete dryness. The small residue is washed, blasted, cooled and weighed. The difference between this weight and the weight previously obtained is the amount of silica. Any considerable amount of insoluble residue must be fused with sodium carbonate and the silica separated as before, the filtrate being added to the main filtrate. One evaporation for the dehydration of the silicic acid, however, is only required.

Alumina and Iron.—The filtrate, about 250 cc., from the second evaporation for silica, is made alkaline with ammonium hydroxide and boiled to expel excess of ammonia or until there is but a faint odor of it. The precipitated iron and aluminum hydroxides after settling are washed once by decantation and slightly on the filter. Setting aside the filtrate the precipitate is dissolved in hot hydrochloric acid, the solution passing into the beaker in which the precipitation was made. The alumina and iron are then reprecipitated by ammonium hydroxide and the second precipitate is collected and washed on the same filter used in the first instance. The filter must, however, first be moistened with dilute ammonia. The filter paper with the precipitate is then placed in a weighed platinum crucible, the paper burnt off and the precipitate ignited, and finally blasted over the lamp for 10 minutes, being careful to prevent reduction. After cooling it is weighed as alumina and ferric oxide, which also contains the small amounts of titanium, phosphorus and manganese present.

Ferric Oxide.—The combined ferric oxide and alumina precipitate is fused in a platinum crucible at a very low temperature with about 10

grams of potassium acid sulphate, the melt taken up with hot water and 25 cc. dilute sulphuric acid. The clear solution is then digested on the steam bath for about 10 minutes, and if great accuracy is desired the small amount of silica filtered off, weighed and corrected with hydrofluoric acid and sulphuric acid. The filtrate is reduced by hydrogen sulphide, boiling out the excess afterwards while passing carbon dioxide through the flask, and titrated with potassium permanganate. This procedure eliminates the influence of titanium.

Lime.—To the combined filtrate from the alumina and ferric oxide a few drops of ammonium hydroxide are added and the solution brought to boiling. To the boiling solution 20 cc. of a saturated solution of ammonium oxalate is added and the boiling continued until the calcium oxalate appears as a well defined granular precipitate. It is allowed to stand for 20 minutes or until the precipitate has settled and then filtered. The precipitate and filter are placed, wet, in a platinum crucible and the paper burnt off over a small Bunsen flame. It is then ignited, redissolved in hydrochloric acid and the solution made up to about 100 cc. with water. Ammonia is added in slight excess and the liquid boiled. The small amount of alumina which is separated is filtered and weighed, and the amount added to that found in the first determination, when great accuracy is desired. The lime is then reprecipitated by ammonium oxalate, allowed to stand until settled, washed, weighed as oxide by ignition and blasting to constant weight or determined with a standard potassium permanganate solution, which method, however, is somewhat questionable as to accuracy.

Magnesia.—The combined filtrates from the calcium precipitate are acidified with hydrochloric acid and concentrated on the steam bath to about 150 cc. 30 cc. of a saturated solution of $\text{Na}(\text{NH}_4)\text{HPO}_4$ are added and the solution boiled for several minutes. It is then removed and cooled by placing the beaker in ice water. After cooling ammonia is added, drop by drop, until the crystalline ammonium magnesium orthophosphate begins to form, and then in slight excess with constant stirring. It is then set aside for several hours in a cool atmosphere and filtered. The precipitate is redissolved in hot hydrochloric acid, the solution made up to about 100 cc., 2 cc. of a saturated microcosmic salt solution added and ammonia, drop by drop, with constant stirring until the precipitate is again formed as described. Allow to stand for about two hours, when it is filtered on paper or in a Gooch crucible, cooled and weighed as magnesium phosphate.

Alkalies.—These are determined by the J. L. Smith method, with or without addition of calcium carbonate to the ammonium chloride.

Sulphur Tri-Oxide (SO_3).—One gram of cement is dissolved in 15 cc. of hydrochloric acid, filtered, and the residue washed thoroughly;

evaporation to dryness is unnecessary. The solution is made up to 250 cc. in a beaker and boiled. To the boiling solution 10 cc. of a saturated solution of barium chloride is added slowly, drop by drop, and the boiling continued until the precipitate is well formed. It is then set aside over night, filtered, ignited and weighed as barium sulphate.

Total Sulphur.—One gram of the material is weighed out in a large platinum crucible and fused with sodium carbonate and a little potassium nitrate over a gasoline or alcohol blast lamp. The melt is treated in a crucible with boiling water and the liquid poured into a tall narrow beaker and more hot water added until the mass is dissolved.. The solution is then filtered.

The filtrate contained in a No. 4 beaker is acidulated with hydrochloric acid, made up to about 250 cc. with distilled water, boiled, the sulphur precipitated with barium chloride as barium sulphate and allowed to stand over night.

Loss on Ignition.—One-half gram of cement is weighed out in a platinum crucible and blasted for 15 minutes. The loss, which is checked by a second blasting, is the loss on ignition.

RAPID OR FACTORY LABORATORY METHODS.

In the laboratories of the cement industry the determination of calcium oxide is, of course, the principal part of the routine work and a number of rapid methods for its determination as well as for the estimation of magnesia have been worked out. These methods are as follows:

1. Titration of the oxalic acid from the washed precipitate of calcium oxalate, decomposed by acid.
2. Titration by the use of standard acid and alkali solutions.
3. Volumetric determination of the carbon dioxide evolved from the calcium carbonate.
4. Volumetric determination of magnesia depending on the fact that magnesia is entirely precipitated from a strongly ammoniacal solution, as magnesium ammonium arsenate by addition of sodium arsenate. The arsenic is determined volumetrically and the magnesium calculated from it.*

Method 1.—In American practice the first method is used most commonly and seems to enjoy the greatest favor among cement chemists. It requires a potassium permanganate solution of such strength that 1 cc.= 0.005 gram calcium carbonate or calcium oxide, depending on whether a raw mixture or burnt cement is to be analyzed. The method is carried out for limestone as follows:

Weigh out 0.5 gram of the finely ground sample into a platinum crucible and ignite over the Bunsen burner to destroy all organic matter.

*"R. K. Meade, *The Chemical and Physical Examination of Portland Cement*," p. 42.

Transfer the sample to a 300 cc. beaker, add 30 cc. of water, cover with a watch glass, add 10 cc. of hydrochloric acid and a little nitric acid. Boil till all the soluble matter is dissolved and all the carbon dioxide expelled. Wash off watch glass and dilute to about 150 cc. with water previously boiled. Add ammonia slightly in excess and heat to boiling. If the insoluble residue is low and it is not desired to weigh the insoluble matter it is not necessary to filter it off. The calcium oxalate is precipitated in the boiling hot solution as usual by the addition of 40 cc. of a hot solution consisting of 20 cc. of concentrated ammonium oxalate solution and 20 cc. of water. Stir for several minutes and let settle for five minutes.

Decant the supernatant solution through an ashless filter, add 40 cc. of hot water, decant, add another portion of hot water and decant for the third time. Now transfer the precipitate to the filter and wash three or four times with hot water. To determine whether or not the precipitate has been washed sufficiently, catch a few cc. of the last filtrate on a watch glass, add a drop of sulphuric and one drop of potassium permanganate solution. If the liquid shows a strong red color the washing is finished, if the color is discharged further washing is necessary. The calcium oxalate is now washed back into the beaker in which it was precipitated, using hot water and diluted to about 200 cc. if necessary. Place the beaker under the funnel and run through the filter into the beaker 30 cc. of dilute sulphuric acid (1 volume of acid to 3 of water). Wash the filter thoroughly with hot water and stir the contents of the beaker while running in the acid. Heat liquid to about 80° C. and titrate with the permanganate solution to a faint pink color which should not disappear for two minutes.

The potassium permanganate solution should not be standardized against iron or ammonium ferrous sulphate, but against calcite checked repeatedly by the gravimetric method of calcium determination.

R. K. Meade* proposes to keep the iron and alumina in solution by the addition of 5 per cent. oxalic acid, the calcium being precipitated by ammonium oxalate and determined volumetrically with a standard permanganate solution. The results have been found by Meade to be very satisfactory.

Method 2.—The acid alkali methods, owing to their rapidity and simplicity, are frequently made use of, but great caution is necessary in their use, and the results should be carefully checked gravimetrically from time to time owing to the fact that these methods are subject to errors. Larger amounts of alumina and iron influence the results most decidedly. S. B. Newberry** proposes the following working method:

Prepare a $n/5$ solution of hydrochloric acid and a $n/5$ caustic soda solution, standardizing with pure Iceland spar, which has been analyzed

* *"Cement and Engineering News,"* June, 1903.

** *"Ibid,"* March, 1903.

gravimetrically. One-half gram of pure spar should exactly neutralize 50 cc. of acid.

Weigh out $\frac{1}{2}$ gram of a finely ground limestone, transfer to an Erlenmeyer flask of about 500 cc. capacity provided with a rubber stopper and a thin glass tube 30 inches long, to serve as a condenser. Run into the flask 60 cc. of the 1-5 normal acid, attach the condenser and boil gently, allowing no steam to escape from tube, for about two minutes. Wash down the tube into the flask with a little water. Remove the condenser and cool the solution thoroughly by immersing the flask in cold water. When quite cold add five to six drops of phenol-phthalein solution (1 gram in 200 cc. alcohol) and titrate back to first pink color with 1-5 normal caustic soda solution. It is important to recognize the point at which the first pink color appears throughout the solution, even though this may fade in a few seconds. If the alkali be added to a permanent and strong red color the lime will come too low. The amount of acid used is called the first acid and the alkali used to titrate back, the first alkali.

In case the materials contain a very small amount of magnesia the operation ends here and the calculation is simply: Number of cc. acid minus number of cc. alkali multiplied by 2×0.56 = per cent. calcium oxide. In this case it is unnecessary to cool the solution, and a permanent red is obtained at the point of neutralization.

The determination of magnesia proceeds as follows:

Transfer the neutral solution to a large test tube 12 inches long and 1 inch inside diameter marked at 100 cc. Heat to boiling and add 1-5 normal caustic soda solution, about one cc. at a time, boiling for a moment after each addition until a deep red color is obtained which does not pale on boiling.

This point can be easily recognized within one-half cc. after a little practice. Note the number of cc. soda solution added to the neutral solution as second alkali. Dilute to 100 cc., boil for a moment and set the tube aside to allow the precipitate to settle. When settled take out 50 cc. of the clear liquid by means of a pipette and titrate back to colorless with 1-5 normal acid. Multiply by 2 the number of cc. of acid required to neutralize and note as second acid.

Calculation:

Second alkali: $\text{second acid} \times 2 \times 0.40$ = per cent magnesia. First acid $\times (\text{1st alkali} + \text{2nd alkali} - \text{second acid}) \times 2 \times 0.56$ = per cent. calcium oxide.

Method 3.—The volumetric determination of carbon dioxide from calcium carbonate, though used to some considerable extent in Europe, has not found favor among American cement chemists, who prefer other volumetric methods. The Cramer-Baur burette is one of the most convenient apparatus for this purpose.

Magnesia.—Prof. N. W. Lord determines magnesia volumetrically by precipitating as magnesium ammonium phosphate, filtering, washing, treating with 1-10 normal sulphuric acid and titrating back with 1-10 normal ammonia, using cochineal indicator.

Ludlow and Harrop Method.—In order to illustrate actual laboratory practice the methods employed at two cement works are given, the first one being used at the works of the National Portland Cement Company, Durham, Canada, having been worked out by Mr. S. H. Ludlow, chief chemist, and Mr. Carl B. Harrop, assistant chemist. Mr. Ludlow has kindly sent the following account of the method:

RAPID METHOD OF RUNNING PORTLAND CEMENT MIXTURES.

The following methods of determining the amount of clay to be added to a given measured quantity of marl in the wet state to produce a correct slurry are based upon the relations existing between the weight and volume of a cubic yard and a cubic centimeter of water.

Required to find the number of pounds of clay to be added to a cu. yd. of marl of any composition or consistency. Take such a volume of the marl that the weight of the total solids in the volume taken, expressed in milligrams, will represent pounds per cu. yd. By a familiar course of reasoning, similar to that employed in establishing the assay ton, the following proportion may be deduced:

Original volume : part taken :: mass represented : part of represented mass taken as unit in analysis.

Let A = Original volume.

Let B = Mass represented or one pound.

Let 1 = Part of represented mass taken as a unit in analysis, or one mgm.

Let X = Part of original volume taken or number of cc. required, so that each mgm. will equal pounds per cu. yd.

Substituting—

$$A : X :: B : 1$$

$$1 \text{ cu. yd.} = 764500 \text{ cc. (or gram of water).}$$

$$1 \text{ lb.} = 453593 \text{ mgm.}$$

Therefore, A = 764500 cc.

$$B = 453593 \text{ mgm.}$$

Substituting and solving for X,

$$764500 : X :: 453593 : 1$$

$$X = 1.685 \text{ cc.}$$

Hence if 1.685 cc. of water (standard conditions) is taken, each mgm. equals 1 pound in the cu. yd. Obviously this will apply to any liquid of whatever density or to a homogeneous mixture of solids and liquids or a thoroughly agitated sample of marl in the semi-liquid state.

Therefore, if 1.685 cc. of marl be evaporated to dryness, in a tared dish, and weighed, its weight expressed in milligrams equals the number of pounds of marl per cu. yd. The weight of marl in a given volume being known, the amount of clay to be added may be readily calculated from the composition of the marl and clay, and the desired composition of the slurry.

Several applications of this principle may be made according to the uniformity of the marl, the system of mixing in the mill and the facilities for correction of slurry, should occasion demand.

METHOD No. 1.

As 1.685 cc. is too small a volume of marl to measure with sufficient accuracy, measure ten times that quantity in a hard glass tube about 95 mm. high by 15 mm. in diameter, calibrated to contain exactly 16.85 cc. Wash into a tared tin or nickel dish, with the jet from wash bottle, using as little water as possible, evaporate to dryness, cool quickly and weigh. For greater accuracy take three samples from top, bottom and center, respectively, of the marl tank and take the average weight of the three samples. Grind the dried samples intimately in an agate mortar. Take two portions, each one-tenth the weight of the dried samples. One portion is analyzed for CaCO_3 by the acid-alkali method. For this purpose $\frac{1}{10}\text{N}$ HCL and $\frac{1}{10}\text{N}$ KOH solutions are the most convenient. The value of one cc of the HCL solution in terms of per cent. of CaCO_3 (or mgms. CaCO_3) should be accurately determined by running a number of average samples of the particular marl in use, a complete analysis having been previously made in each case by a standard method. This standardization of the solution with the marl to be used is very essential as the ease with which the acid attacks other constituents of the marl besides the CaCO_3 varies considerably in different marls. In the second portion of the dried sample the clay matter is determined by precipitating the silica, alumina and iron together, with ammonia and eliminating their combined weight in the usual way.

We now have a number of pounds of clay matter and of calcium carbonate in each cu. yd. of the tank marl.

Let A = Pounds of CaCO_3 .

B = Pounds of clay matter.

C = Factor representing pounds CaCO_3 required to satisfy one pound of clay matter in the marl.

D = Factor representing number of pounds of CaCO_3 required for each pound of clay to be used.

X = No. lbs. clay required per cu. yd. of marl.

Solve for X by the following formula:

$$\frac{A - (B \times C)}{D} = X.$$

METHOD No. 2.

To avoid the necessity of determining the clay matter in the marl, first make a number of preliminary analyses of the particular marl bed to be worked to determine the combined per cent. of calcium carbonate, silica, alumina and iron in an average sample of marl. From samples of tank to be analyzed take as before, samples of 16.85 cc. each, evaporate to dryness in a tared dish, cool and weigh. One tenth the number of milligrams in the dry sample equals pounds of marl per cu. yd. Take 1 gm. for analysis and determine by $\frac{1}{10}\text{N}$ HCL and $\frac{1}{10}\text{N}$ KOH solution (standardized as in method No. 1) the per cent. of CaCO_3 (or CaO as desired.)

Let A = Pounds of marl per cu. yd.

B = Per cent. of CaCO_3 in marl.

a = Combined per cent. of clay matter and CaCO_3 as previously determined to be the average of marl used.

C = Factor representing number lbs. CaCO_3 required for one lb. of clay matter in marl.

D = Factor representing number of lbs. of CaCO_3 required for one pound clay used.

X = Pounds of clay required per cu. yd. of marl.

Solve for X by the following formula:

$$\frac{(A \times B) - C \times (a - B) \times A}{D} = X.$$

By practice the analyst is able to discriminate between the clay matter and organic matter in the flask during the period of boiling with the acid solution and after titrating back with the alkali solution, and the per cent. of clay can be judged with sufficient accuracy after the percentage of CaCO_3 has been determined. In doubtful cases where the marl shows unusual irregularity in CaCO_3 , the contents of the flask may be thrown on the filter and the clay matter quickly determined by ignition. This, however, is seldom found necessary.

METHOD No. 3.

From each of several samples taken from different parts of the tank marl, take a small sample, say 20 cc., measured in a wide tube. Introduce into a dry 6-inch porcelain mortar, no water being used in transferring from the tube to the mortar. Grind the marl to an impalpable condition when the mass should be absolutely homogeneous. From this take for analysis 3.37 cc. ($=2 \times 1,685$ cc.) this being a sufficient quantity when properly manipulated and requiring a convenient quantity of $\frac{1}{2}\text{N}\text{HCl}$ for analysis. This can best be accomplished by the use of a pipette constructed according to accompanying cut. The pipette should be carefully dried before filling with marl and the marl all carefully removed with a jet of water. $\frac{1}{2}\text{N}\text{HCl}$ and $\frac{1}{2}\text{N}\text{KOH}$ solutions standardized as in method No. 1 are employed for analysis, 50 cc. of the HCl solution being used for a determination. By the use of a table expressing the value of any number of cc. of HCl solution (the number of cc. liable to be used being determined by trial) in terms of milligrams of CaCO_3 , the number of pounds of CaCO_3 is read direct.

Example.—If each cc. HCl is found to equal 2.435 per cent. CaCO_3 in 1 gram $=24.35$ mgms. CaCO_3 and we find that 3.37 cc. marl requires 45 cc. HCl , then $24.35 \times 45 = 1095.71$ mg.

$1095.71 \div 2 = 547.8$ pounds CaCO_3 per cu. yd. of marl. The amount of clay to be added is figured by the aid of the formula employed in method No. 1.

$$\frac{A-(B \times C)}{D} = X.$$

B may be determined on an average sample as in method No. 2, or in case of irregularity of marl the contents of the flask are thrown on the filter, ignited and weighed. We have thus the pounds of CaCO_3 and of clay matter per cu. yd. and proceed with the calculation of clay matter required as in method No. 1, though not always so accurately as method No. 1 and 2. This last method is especially advantageous because of the rapidity of manipulation, 20 minutes being sufficient for analysis and calculation of results. When the marl is sufficiently uniform and the plant is so arranged as to admit of the proper correction when necessary, remarkable uniformity may be obtained with a minimum of time and labor.

The above methods have all been found to give excellent satisfaction in cement practice, having been used according to the condition to which each was best suited in various cement plants in the United States and Canada.

Fisher's Method.—The following working method is used by Mr. Fred Fisher, chemist of the Newaygo Portland Cement Company. In employing this method Mr. Fisher has succeeded in completing, without help, eight analyses in an eleven hour shift, besides doing other routine work, but the ordinary procedure is to make seven exact analyses of slurry in 24 hours, employing, of course, a night assistant.

PREPARATION OF THE SAMPLE.

About a quart of the wet mixture or slurry, taken from a well-agitated tank, is brought to the laboratory. It is passed through a sausage grinder. This breaks up

any shells or other lumps and helps to insure a homogeneous sample. About 50 or 60 cc. are poured out thin on a hot electric griddle, where it dries in a few moments. The dry sample is ground fine in a mortar without sifting.

DRYNESS.

A small wide-mouth bottle is filled with the slurry and leveled off. About 20 cc. is poured into a tared pan, in which it is dried on the hot plate and then weighed. The bottle, without being cleaned, is filled with water from a burette, indicating the amount of sample taken. From this and the weight, as above, a factor is obtained with which to calculate the amount of material in a measuring tank. "Weight" divided by "burette reading" equals "dryness," which multiplied by the capacity of the tank in litres would give the number of kilos of dry material.

ANALYSIS.

0.5 g. of the sample and 5 g. sodium carbonate are mixed in a thirty cc. platinum crucible and fused over a blast lamp. After the charge is melted it is poured out on a

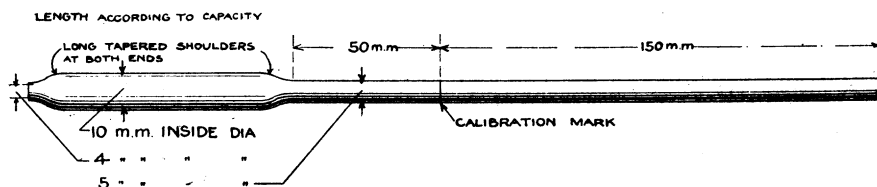


Fig. 11. The Ludlow and Harrop marl pipette, to contain 3.37 c.c.

clean carbon plate. With the aid of a dropper the crucible and cover are cleaned and rinsed with a minimum of 1 to 1 hydrochloric acid, into a No. 6 evaporating dish. The lump of fused material is dropped in and about 15 seconds later 10 cc. of concentrated hydrochloric acid is added, the dish is covered with a watch glass and set on a water bath. After all effervescence has ceased and it has steamed a moment, to automatically rinse any spattering from the covering, the latter is removed and set aside to be used later. With this minimum amount of liquid the fused mass is all decomposed, but part of the sodium chloride and most of the silica is precipitated by the strong acid. This precipitate being dense and granular stays at the bottom of the dish, and the evaporation proceeds more rapidly than usual, without scumming over or caking, and is finished in twenty to thirty minutes; when especially hurried the evaporation is hastened by playing on the surface of the liquid with a Bunsen flame.

When entirely free from smell of acid the dish is removed from the water bath. After wetting the saline mass with hot water, 10 cc. concentrated hydrochloric acid is added, the sides of the dish washed down with hot water, covered with the watch glass and set on the hot plate to boil a moment. With the aid of the filter pump and bell jar the solution is filtered into a 600 cc. Griffin beaker through an 11 cm. ashless filter. The dish is rinsed out with hot water and the filter washed twice. The funnel with the filter is transferred to a filtering flask, the dish cleaned out with the aid of a finger cot and rinsed into the filter, and the latter washed twice more. By the above procedure practically all the soluble part of the sample is in solution, and its volume kept low. The filter is burned and ignited over the blast lamp, and the silica transferred from the platinum crucible to a tared watch glass and weighed.

To the filtrate are added a couple of drops of strong bromine water and 20 cc. of a mixture of ammonia and ammonium chloride. This mixture is of such a degree of strength that the above amount will contain ammonia enough to neutralize the 10 cc. of

acid that is in the solution, and furnish slight excess, some additional ammonium chloride is also added at this point. The beaker is set on the hot plate and the solution boiled a moment until it has ceased foaming. Without waiting for it to settle it is filtered by suction into an 800 cc. Griffin beaker through an 11 cm. ashless filter. After rinsing out the beaker the filter is washed three times with hot water. The filter is burned and the iron oxide and alumina weighed.

The solution in its larger beaker and about 30 cc. of a saturated solution of ammonium oxalate in a smaller one are then set on the hot plate and after both are boiling the latter is added to the former, which is boiled a moment longer. It is immediately filtered with the filter pump and bell jar through an 11 cm. filter into a little flask, the beaker well rinsed out and the filter washed twice, then transferred with the funnel to a filtering flask and the washing continued. The filter is then removed from the funnel, opened out flat on the palm of the hand and the oxalate of lime washed back into the beaker in which it was precipitated. About 30 cc. 1 to 3 sulphuric acid and 300 cc. hot water are added to dissolve the oxalate, and the lime is determined by titration with standard permanganate. This solution is of such strength that using 0.5 g. of sample each cc. is equivalent to one per cent. of lime.

To the filtrate in the flask, cooled in running water, is added about 10 cc. of a strong solution of microcosmic salt and 100 cc. of strong ammonia, a rubber stopper inserted and the whole well shaken for five minutes. This throws down the magnesium ammonium phosphate quite dense and granular, with no tendency to stick to the flask. After standing half an hour the solution will have separated out clear about half an inch. It is then filtered with the filter pump, rinsing out the flask and washing well with 1 to 6 ammonia, the filter is wet with a strong solution of ammonium nitrate ignited, weighed and the magnesia calculated as usual.

INSOLUBLE RESIDUE IN RAW CEMENT MIXTURES AND BURNT CEMENT.

In raw cement mixtures it is important to estimate the so-called insoluble residue for the purpose of determining whether or not the grinding has been carried sufficiently far so as to bring about complete or sufficient chemical union of the cement ingredients. It is of special value in new plants, particularly those working with a limestone-clay mixture. It is not necessary to carry on this determination after the rate of feeding the tube mills has been adjusted, but it will always prove a valuable check on the work done by the grinding machines.

The analysis proper simply consists in heating a one-gram sample over the blast lamp for 20 minutes, treating it with hydrochloric acid and alkaline solutions, as described repeatedly under the head of pozzolanes and rational clay analysis. Properly ground raw mixtures should show little or no residue. Any appreciable residue is due to insufficient grinding. Of course a sieve analysis would show the condition of fineness of a mixture, but, after all, could not differentiate the real condition governing chemical union as well as does this mineral analysis. Analogous to the determination of the "insoluble residue" in the raw mixture, we can apply the same method to the burnt cement, with the exception that here the carbon due to unconsumed coal mingled with the cement must be burnt out. If this is done either before the analysis or at the end, before weighing up the residue, the latter will be found to consist of any coarse quartz not united with the lime, and any ash

usually in very small amount, which had no opportunity of being acted upon chemically by the basic cement mixture. The coarse quartz grains can, however, be easily distinguished by their gritty feeling, or definitely proven by means of a magnifying glass or microscope. For good Portland cement this insoluble residue, free from carbon, should be practically nothing; any appreciable amount should arouse our suspicion as to the quality of the cement. But this is not invariably true. There may be mixtures which, when burnt, contain some insoluble quartz, yet in these it should be carefully determined and allowed for in the calculation of the batch. Still, such cases are uncommon, and the above caution must be allowed to stand. In all cases finer grinding will cause the insoluble residue to disappear.

Supplementary Physical Methods.—Of physical methods of examination which might be employed we will mention only two, the determination of the heat of hydration of calcium oxide and microscopic examination.

It has been suggested to calculate the amount of calcium oxide or carbonate present in a limestone by heating it over the blast lamp so as to expel all of the carbon dioxide and then determine the heat of hydration in a calorimeter. Knowing that one gram. of pure calcium oxide on hydration evolves 269.6 calories, one might suggest that by the use of a suitable factor, obtained by a number of gravimetric analyses for a given limestone, the amount of calcium might be calculated. In a great number of experiments made with limestone, using the calorimeter and calcareous mixtures for other purposes of investigation, the Ohio Survey has shown that so many factors affect the results obtained that it would not be advisable to employ methods based on this heat reaction, especially as the time saved is not worth the trouble.

Conditions are different, however, with the examination of burnt cement, where it is desirable to judge the material with reference to the uncombined lime present, so as to be able to determine the time of curing and other important facts. Here the calorimeter becomes a valuable instrument whose intelligent use will bring to light important data. The application of the calorimeter for this purpose will be more fully discussed under the head of the testing of Portland cement.

Microscopic examination, although hardly ever made absolutely necessary, frequently becomes a helpful aid in detecting the presence of foreign substances in a cement, like carbon, underburnt cement or slag, which can be distinguished by the difference in color and general appearance. In the mechanical analysis it enables one to make measurements of particles from sediments. In working with a cement which has a tendency to dust, or show abnormal behavior, the microscope may be able to show the cause of the trouble by proving the presence of non-hydraulic crystalline bodies.

DETERMINATION OF CARBON AND COAL ANALYSIS.

This determination is best made by means of the usual carbon train or the Shimer crucible. Though the carbon determination is hardly ever necessary for the raw materials, it will give useful data in regard to the carbon left unburned in the cement.

The ultimate analysis of coal is made in very few, if any, cement works but an occasional proximate analysis, determining the volatile combustible matter, the fixed carbon, moisture and ash, is very necessary. The question of the ash from coal is too much neglected in American cement practice; its influence upon the cement composition is very marked in some instances. The subject of the effect of the ash upon the cement should be carefully studied by every cement chemist for his particular cement and coal. For this purpose it is necessary, of course, to analyze the ash, which is done by treating it like clay, fusing with sodium carbonate, and separating the silica, alumina, ferric oxide, lime and magnesia as usual.

It need hardly be emphasized that the amount of sulphur in coal should receive careful consideration. With the present rapid methods of analysis available, there is no excuse for neglecting this important determination. An admirable method of rapid sulphur determination has been worked out by J. D. Pennock and D. A. Morton in the laboratory of the Solvay Process Co.*

ANALYSIS OF THE KILN GASES.

The most faithful representation of what takes place in a furnace of any kind is given by the analysis of the gases as they flow into the stack. It gives an accurate record of just what efficiency has been attained, whether too much or not enough air has been admitted. And yet our cement mills seem to ignore this valuable aid entirely, and do not seem to care to know whether or not they are exercising fuel economy. In some cases on record it is evident that from 10 to 35 per cent. or more fuel is being wasted which might be saved. The writer is not now speaking of the losses inherent in the present rotary kiln, but losses due simply to excess of air in burning.

Gas analysis is easily carried out by means of the well-known Orsat apparatus, requiring but little time and trouble. By means of a pipe system ($\frac{3}{8}$ -inch pipe) and a water syphon, samples of gas may be drawn continuously from any particular kiln, and the analysis carried on in the laboratory, or by means of a portable sampler, easily and cheaply made from gas piping. The contrivance may be set up at a kiln, the desired number of samples drawn and then taken to another kiln. The sample is drawn through a $\frac{3}{4}$ -inch pipe projecting from 2 to 4 feet into the upper end of the rotary kiln, the pipe being plugged at the end and

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perforated for about 12 inches. It is obvious that the pipe should not be too close to the circumference of the kiln in order not to be hit by any lumps of material which might cling to the kiln lining. Of course there is little danger of this where a dry mixture is used. The pipe should be rinsed with a solution of borax which will produce a kind of glaze on the inside. If possible it is run straight out through the brickwork of the stack; outside of the kiln the $\frac{3}{4}$ -inch pipe reduces to $\frac{3}{8}$ inch. Of course, a pipe system connected to every kiln and permitting of sampling the gas from any particular kiln simply by turning on the water syphon in the laboratory is most convenient, but is by no means necessary. This is especially true since, after the proper rate of feeding the coal and blowing in of the air have been established on the basis of gas analysis, but very few analyses may be necessary. Needless to say, all the pipe fittings must be made as air-tight as possible.

Owing to the familiarity of the Orsat apparatus a description of it and the simple mode of operating it are unnecessary. With practice a gas analysis can be made in a very short time (about 15 minutes). A detailed description of the working of this instrument, together with the mode of sampling, etc., is found in Lord's Metallurgical Notes, and other books on metallurgical or gas analysis.

In calculating the per cent. of air corresponding to the gas analysis in question we must remember that the composition of the waste gases from a lime or cement kiln shows an excess of carbon dioxide, due to the decomposition of the calcium carbonate. Any calculation, therefore, depending solely upon the carbon dioxide content shown by the analysis is bound to be erroneous. In order to show the relations existing between the air admitted and the per cent. by volume of carbon dioxide, oxygen and nitrogen given by the analysis, a short discussion of the principles governing the evolution of gases from the fuel will be found advisable.

If the fuel used were pure carbon and no carbon dioxide from other sources could mingle with the gases the composition of the waste gases would invariably be 79 per cent. by volume of nitrogen and 21 per cent. of carbon dioxide, provided complete combustion took place, and no excess of air was admitted. If excess of air was admitted the sum of the per cent. of carbon dioxide and oxygen would be practically equal to the constant value, 21. But coal contains besides carbon, hydrogen (hydrocarbons) which also consume oxygen, so that the per cent. of carbon dioxide is correspondingly decreased. The one constant factor in the gas analysis is furnished by the nitrogen, which undergoes no change, being chemically inert, and hence it furnishes the most reliable basis for the calculation of the air admitted in the combustion of the fuel. The proportion of the nitrogen present in the air to the oxygen content of the latter is invariably in the ratio of 79:21, by volume, or for every volume

of oxygen we have 3.76 volumes of nitrogen. If, now, we let N be the total per cent of nitrogen found by analysis and O the per cent of oxygen determined, the amount of nitrogen, n_1 , corresponding to the amount of air really made useful in the combustion must be equal to $N - n$, or, making

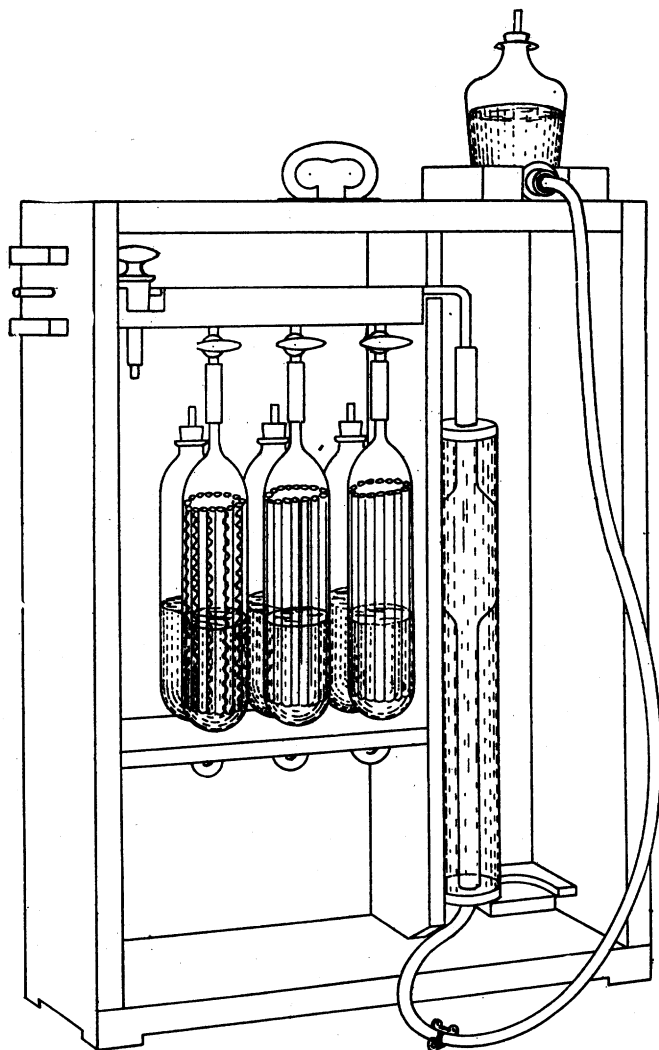


Fig. 12. The Orsat apparatus for gas analysis.

use of the per cent. of oxygen found, $n_1 = N - 3.76O$. Thus, without calculating the amount of air itself, we can obtain the ratio between the air introduced and the air used by making use of the ratio of nitrogen brought in and the nitrogen of the air really deprived of its oxygen, which is the same thing as if we compared the volumes of air proper.

In this manner the ratio of total and useful air is obtained by the expression $N \div (N - 3.76O)$. We can readily convert this into per cent.

by volume by multiplying the numerator by 100, making the expression $100N \div (N - 3.76O)$. We must remember that N here is always the per cent. by volume of nitrogen as found by the gas analysis, and O the per cent. of oxygen. The resulting expression is a value either above or below 100, depending on whether the conditions of firing are oxidizing or reducing. For theoretically perfect conditions, that is, when only just enough air is admitted to burn the fuel, no oxygen is shown by the analysis, and hence the ratio is $100N \div N$ or 100. Therefore 100 per cent. of air is the ideal towards which all in charge of purely heat producing furnaces must strive. If, for example, a ratio of 160 per cent. is shown by the above calculation, it tells that an excess of 60 per cent. of air has been admitted.

On the other hand, an amount of air lower than 100 per cent. stands for a deficit of air proportional to the lack of oxygen. Such an analysis shows but little oxygen, and indicates the presence of combustible gases, especially of CO. Any amount of combustible gases present will thus stand for minus oxygen, so that the formula becomes $100N \div [N - (-3.76O)]$ or $100.N \div N + 3.76O$.

To illustrate, a gas analysis shows the following composition by volume:

Carbon dioxide,	14.3 per cent.
Carbon monoxide,	4.1 per cent.
Oxygen,	0.2 per cent.
Nitrogen.	79.8 per cent.

To calculate the amount of air entering the furnaces. Carbon monoxide represents an unburnt gas consuming for complete combustion one-half its volume of additional oxygen, or $4.1 \div 2 = 2.05$ volumes of oxygen, which is necessarily minus in sign. But as the analysis shows 0.2 per cent. of free oxygen the minus oxygen will be $2.05 - 0.2 = 1.85$ per cent. Substituting in the formula we have, $100 \times 79.80 \div 79.80 + (3.76 \times 1.85) = 91.9$ per cent. of air admitted, or the deficit of air as shown by this analysis is 8.1 per cent. These simple calculations are the ones most commonly required in the examination of the firing conditions of boilers and kilns, and all the data for it are furnished by the Orsat apparatus. More complicated and accurate apparatus, while important for scientific research, is unnecessary in practice, though the Elliot apparatus may be used to determine the hydrocarbons without difficulty.

In some investigations it is desirable to know just what part of the oxygen of the air is used for converting the carbon of the coal to carbon dioxide, and what part burns the hydrogen of the coal to steam. This calculation is illustrated by the following example. Assuming that the coal used contains

83.75 per cent. carbon
4.13 per cent. hydrogen
2.68 per cent. oxygen.

we find that the available hydrogen is $4.13 - \frac{2.68}{8} = 3.80$ per cent.

Now 83.75 parts by weight of carbon require $\frac{32}{12} \times 83.75 = 223.32$ parts of oxygen, while the hydrogen requires $3.8 \times 8 = 30.40$ parts of oxygen, the total parts by weight of oxygen for 100 parts of the coal being thus $223.32 + 30.40 = 253.72$. Since the air contains 21 per cent. by volume of oxygen there are used for the combustion of the carbon.

$$\frac{21 \times 223.32}{253.72} = 18.49 \text{ volumes of oxygen.}$$

The hydrogen requires

$$\frac{21 \times 30.4}{253.72} = 2.52 \text{ volumes of oxygen.}$$

But every volume of oxygen on combustion furnishes one volume of carbon dioxide; therefore on using the above coal the ratio of the carbon dioxide to the nitrogen must be 18.49:79.

In the burning of cement, where a considerable amount of the fire gases is made up of carbon dioxide from the decomposition of the calcium carbonate, it may be desirable to know the amount of the CO_2 present in the gases resulting from the limestone. Knowing the total amount of carbon dioxide shown by the analysis we can calculate the amount of this gas due to the combustion alone from the percentage of air represented by the analysis as calculated from the expression, $100\text{N} \div \text{N} - 3.76\text{O}$.

If we let the per cent. of air be equal to a , and assuming that a coal is used of the composition given above, the carbon dioxide produced in the combustion must be obtained by the expression $79:18.49 = \frac{\text{N}.a}{100}:X$ or

$X = \frac{\text{N}.a \times 18.49}{100 \times 79}$ If, for example, the nitrogen found by the analysis is 69 per cent., the air used = 95 per cent. and the carbon dioxide = 30 per cent. the CO_2 produced by combustion must be: $\frac{69 \times 95 \times 18.49}{100 \times 79} = 15.34$ per cent. and the carbon dioxide evolved from the limestone must be $30 - 15.34 = 14.66$ per cent.

MECHANICAL ANALYSIS OF RAW MIXTURES AND CEMENTS.

Sieve Analysis.—The fineness of grain of the mineral constituents of a clay governs to a large extent its chemical activity, and hence it becomes an important and interesting problem to bring about a separation of the various sizes of grain. The simplest and most obvious method of separation is the sieve analysis, in which the material to be examined is passed either in a dry or wet state through a series of sieves. The usual combination for a sieve analysis as practiced in the laboratory of

the Ohio Geological Survey comprises the 20, 40, 60, 80, 100, 120, 150 and 200 mesh sieves, these being small copper frame affairs conical in shape, $3\frac{1}{4}$ inches in diameter at the top and $2\frac{1}{4}$ inches at the bottom. These sieves are readily put together, telescope-like in a vertical arrangement, so that the coarsest sieve, No. 20, is at the top, the finest at the bottom. By making a weighed amount of materials up into a thin slurry with water, using, say, 10 grams, the separation is effected by pouring the liquid mixture through the top sieve, washing out the beaker and playing a fine stream of water from a water bottle on the sieve until no more can be washed through. It is then placed on a watch glass and dried in a laboratory drying oven. When dry and cooled the sieve and its contents are weighed. The weight of the dry sieve alone has been previously determined. The difference between the gross and the net weights of the sieve will, of course, give the weight of the residue. Similarly, the weights of the residues on the remaining sieves are determined readily and quickly.

If it is desired to make a sieve analysis of a cement, water evidently cannot be used, but it is necessary to work with alcohol, redistilled over caustic lime. The separation is effected just as in the case of the clay mixtures.

Analysis by Sedimentation.—For the separation of grains passing through the 200 mesh sieve we must employ another means of differentiation. Two principles are commonly used in the classifying of fine particles, suspension and elutriation.

The first is obviously the simplest mode of separation, the practical difficulties being in securing perfect separation of the particles, in preventing flocculation and in avoiding currents. The particles may be prevented to a large extent from flocculation by boiling and the addition of a little ammonia.

In regard to the theory governing the fall of small grains while in suspension in a liquid, Rittinger has given a formula, the equation of a parabola, which expresses the relation between the velocity in meters, V , the diameter of the particles, D , and the specific gravity, d , for average particles as follows:

$$\frac{V}{D} = 2.44(d-1)$$

Wagoner, on the other hand, has found that the parabolic formula does not apply, but has derived a formula for fine grains expressing the relation between the diameter and rate of fall, viz.:

$$V = c \sqrt{\frac{D^{3/2}}{aD^2 + b}}$$

where V is the velocity in mm. per second; D is the diameter of the particle in mm. and a , b and c are constants.

For quartz with a specific gravity of 2.64, $c=100.4$, $a=0.903$ and $c=0.5195$.

R. H. Richards¹ gives the following values for the velocity of the fall of quartz for various coarser diameters:

Diameter in mm.....	0.16	0.22	0.33	0.51	0.81	1.36
Velocity in mm. per second...	32	45.2	64.0	90.5	128	181

A satisfactory method of carrying out this sedimentary analysis is given by Osborn,² who makes three separations of particles ranging from 0.25 to 0.05 mm., 0.05 to 0.01 mm. and from 0.01 mm. diameter to fine dust. He uses a sample of 30 grams and passes the material through sieves. For carrying out the work he simply places the sieved material into a beaker, adding water and allowing the sediment to settle a short time.

"The turbid liquid is then decanted from the sediment and after standing until a slight deposit has formed is again decanted and the sediment examined with a microscope. If sand (0.25 to 0.05 mm.) is present, the subsidence of the turbid liquid is continued until no more sand is deposited. As the sand subsides rapidly there is no difficulty in altogether freeing the liquid first decanted from this grade of particles. The sediment thus obtained contains all the sand, a part of the dust (0.01 mm. and finer) and much silt (0.05 to 0.01 mm.). As only dust and the finest silt render the water turbid, the sediment is stirred a few times with a fresh quantity of water and decanted after standing long enough to let the sand settle. When the water is decanted free from turbidity, the last portions passing through the sieve with clear water are added to the sediment and the decantation continued so as to remove most of the silt. When no more silt can be easily removed from the sediment without decanting sand, the decantations are made into a different vessel and the subsidence so timed as to remove as much of the silt as possible.

"By using a little care at least three-quarters of the sand are thus obtained free from silt. The rest of the sand is mixed with the greater part of the silt, which has been decanted into the second vessel. The size of the smallest particles in this vessel is determined with the microscope, to make sure that its contents are free from dust, as they usually will be if, after settling for a few moments, they leave the water free from turbidity.

"The material is thus separated into three portions, one containing sand, one sand and silt, and the other silt, dust and impalpable powder,

¹ *Ore Dressing*, p. 489.

² *H. W. Wiley, Agricultural Analysis*, p. 196.

clay. The sand and silt are separated from each other by repeating the subsidences and decantations in the manner just described.

"In this way there is removed from the sediment, on the one hand, a portion of silt free from sand and dust, and, on the other hand, a portion of sand free from silt; then is obtained a second intermediate portion consisting of sand and silt, but less in amount than the first and containing particles of diameters much more nearly approaching 0.05 mm. By repeating this process a few times this intermediate portion will be reduced to particles whose diameters are very near 0.05 mm. and which may be divided between sand and silt, according to judgment. The amount of this is usually very small. As soon as portions are separated which the microscope shows to be pure sand or pure silt, they are added to the chief portions of these grades already obtained.

"The same process is applied to the separation of silt from dust. When all the silt has been removed from the dust and clay, the turbid water containing the dust and clay is set aside and allowed to settle in a cylindrical vessel for 24 hours. The vessel is filled to a height of 20 cm. According to Hilgard, the separation of the dust from the clay during a subsidence of 24 hours will give results of sufficient accuracy, although the clay then suspended will not be entirely free from measurable fine particles up to .001 or .002 mm. diameter.

"Small beakers and small quantities of distilled water are used at first for the decantations, as thus the duration of subsidence is less and more decantations can be made in a given time. Beakers of about 100 cc. capacity are convenient for the coarser grades, but it is necessary to use larger vessels for the fine sediments from which turbid water accumulates that cannot be thrown away, as may done with the clear water, from which the coarse sediments settle out in a short time. The water should be kept as small in amount as possible.

"Pestling with a soft rubber pestle and boiling will help to break up the fine lumps of clay.

"A mechanical analysis is made in about 5 or 6 hours, exclusive of the time necessary for collecting the dust and separating the clay, for which a subsidence of 24 hours is allowed.

"The sediments are prepared for weighing by allowing them to subside completely, decanting the clear water as far as possible, rinsing them into a weighed platinum dish, evaporating and igniting. The dish is cooled in a dessicator."

Although soil analysis for agricultural purposes requires great exactness as to the percentages of very fine material, for the purpose of the cement industry this very elaborate differentiation is not necessary. The cement chemist requires to know only how much of a clay is mechanically fine enough for the chemical reaction involved. Generally speaking, we might say that everything passing the 150 mesh sieve (150 mesh to

the linear inch) is sufficiently fine for chemical reaction. But we must not lose sight of the fact that, though reaction by virtue of a higher heat or more lime might be made to take place with particles close to 150 mesh size, after all the most important role is played by much finer grains which cannot be differentiated by mere sieving. The real cement producing magma of Portland cement is formed from the very finest particles of the clay which on vitrification draw the coarser grains into combination. When the potter melts his fritt for a glaze in a crucible, the fine and more fusible portions melt first and gradually bring the coarser and more refractory material into fusion. It becomes important, therefore, to select clays which contain the greatest amount of fine grained matter.

The Ohio Geological Survey has undertaken to study this matter from the practical standpoint. Potter's flint, or finely ground quartzite, was first made the subject of an examination. When mixed with calcium carbonate and heated to 1100°C, it showed on treatment with hydrochloric acid and sodium carbonate solutions, a residue of 28.83 per cent., 71.17 per cent. having gone into solution.

The first thing to do was the carrying out of the sieve analysis, but owing to the fact that sieves differ widely in mesh it was thought necessary to make measurements of the mesh of the different sieves, which are given in the following table:

No. of Sieve.	40	80	100	120	150	200
Space between wires, in inches.....	0.0087	0.0074	0.0060	0.0051	0.0038	0.0031
Remarks.....	Slightly irregular	Regular	Regular	Somewhat irregular	Regular	Regular

The spaces given are the averages of 50 micrometer readings. In the sieve analysis of the flint the following results were obtained:

	Per cents.
Left on 120 mesh sieve.....	1.40
Left on 150 mesh sieve.....	2.36
Left on 200 mesh sieve.....	1.06

In considering the results of a sieve analysis it must be remembered that the particles passing through the sieve are not necessarily round or symmetrical in shape, but may often be needle-like in form, and though they pass through the sieves they are apt to be larger in bulk than particles retained which approach the more ideal spherical shape.

The portion of the flint washed through the 200 mesh sieve was transferred to a 250 cc. beaker and enough water added to make 200 cc. of liquid. The water was now stirred and allowed to settle for one minute

and the supernatant liquid was syphoned off carefully. This operation was repeated till the washings were clear. The residue in the beaker was removed, dried and weighed. Then the washings that had been removed were boiled down to 200 cc., stirred as before and allowed to settle for three minutes and syphoned off. This was continued until finally after three minutes the supernatant liquid was clear. The residue was dried and weighed as before. The third washing was collected, stirred, allowed to settle for nine minutes, syphoned and washed as before. The same operation was repeated for 27 and 81 minutes' settling.

The syphon, with rack and pinion for adjusting its level above the bottom of the beaker, and glass stop cock for controlling the rate of flow together with the sieves, microscope, etc., used in this method of analysis are shown in Fig. 12.

The sediments in each case were carefully examined under the microscope and measurements made of the grains. In the table marked A on page 153 the measurements of particles found in two samples of flint are given. The average dimensions represent 45 measurements.

Since in cement clays the question of the fineness of the quartz grains is the most important question, and since practically everything else offers no difficulty to the chemical combination, this table should prove of some assistance to the cement chemist in making use of the suspension method of mechanical analysis.

The flint samples mentioned, when analyzed mechanically as given in the method above, showed the average results given in Table B, page 153.

This mechanical analysis represents probably the greatest fineness practiced in commercial dry grinding for the clay industries at the present time.

The fact remains, however, that the cement chemist has but little time at his disposal in the daily rush of his routine work, and the mechanical analysis, if made at all, must be carried out rapidly. It is possible to obtain results sufficiently valuable by making only one sedimentation, with one minute settling, obtaining the amount of all particles finer than this sediment, 0.0021 inch, by difference.

Thus the process might be carried out as follows: Weigh out 5 grams of the sample, make up into a thin slurry and wash cleanly through the 40, 100, 150 and 200 mesh sieves. The washings from the last sieve are caught in a 250 cc. tall, narrow beaker, stirred, allowed to settle for one minute and the supernatant liquid syphoned off. Fresh distilled water is now added to the sediment in the beaker, thoroughly stirred, allowed to settle for one minute and syphoned off as before. This is repeated till the water added to the sediment no longer is turbid. After the last decantation the residue is transferred to a weighed porcelain or metal dish and weighed. The sum of the weight of the residues on the four sieves

plus the weight of the sediment subtracted from 5 grams will give the weight of all the particles finer than the one-minute sediment. The addition of a drop or two of ammonia or boiling the water will usually deflocculate any aggregate of clay particles. This mechanical analysis works especially satisfactorily with limestone, clay and raw cement mixtures and it is possible to carry out this analysis in one hour.



Fig. 13. Syphon and apparatus for analysis by sedimentation.

Mechanical Analysis of Ground Cement.—The same process may be carried out with ground cement, but in place of water some liquid not acting upon the cement must be used. Alcohol redistilled over caustic lime was

Table A.—Showing Dimensions of Grains of Flint Obtained in Different Sedimentation Periods.

	Maximum dimensions found, in inches.		Minimum dimensions found, in inches.		Average diameter (average of 45 measurements) in inches.	
	No. 1.	No. 2.	No. 1.	No. 2.	No. 1.	No. 2.
1 minute settling.....	0.008	0.0088	0.0008	0.0004	0.00212	0.00210
3 minutes settling.....	0.0032	0.0016	0.0004	0.0002	0.00086	0.00088
9 minutes settling.....	0.00096	0.00110	0.00014	0.00014	0.00041	0.00044
27 minutes settling.....	0.00055	0.00055	0.00003	0.00007	0.00026	0.00026
81 minutes settling.....	0.00055	0.00048	0.00003	0.00003	0.00013	0.00014

Table B.—Mechanical Analyses of Potters' Flint, by Sieves and Sedimentation.

No.	Left on 40 mesh sieve, Per cent.	80 mesh, Per cent.	100 mesh, Per cent.	120 mesh, Per cent.	150 mesh, Per cent.	200 mesh, Per cent.	1 minute settling, Per cent.	3 minutes, Per cent.	9 minutes, Per cent.	27 minutes, Per cent.	81 minutes, Per cent.	240 minutes, Per cent.	720 minutes, Per cent.	Re-Per cent.
	†	†	†	†	†	†	†	†	†	†	†	†	†	†
1	0.02	0.12	0.282	0.71	1.05	1.24	23.94	18.93	8.50	7.44	5.74	1.59	0.22	30.21
2	0.01	0.20	0.48	0.78	2.36	1.06	24.74	17.84	9.30	8.02	7.04	1.63	....	....
Av. diam., inch.	0.0087	0.0074	0.0060	0.0051	0.0038	0.0031	0.0021	0.00086	0.00041	0.00026	0.00013	....	....	....

†From dimensions of space between wires of sieves.

used very satisfactorily. Careful tests by Professor Edward Orton, Jr., of the dissolving action of alcohol upon cement showed that practically nothing was brought into solution.

The specific gravity of the alcohol used fluctuated around 0.811. In determining the sizes of the various sediments a well-known brand of Portland cement was used and the following results were obtained:

Sediment.	Maximum size in inches.	Minimum size in inches.	Average size in inches.
1 minute settling	0.008	0.0002	0.00200
3 minutes settling	0.002	0.0002	0.00072
9 minutes settling	0.00075	0.00007	0.00030
27 minutes settling	0.00034	Too small to measure	0.00020

The average size is obtained from 50 measurements.

Under the head of physical testing of Portland cement attention will be called to the importance of the mechanical analysis of cement.

Analysis by the Elutriation Method.—This fine method depends on the fact that the carrying power of a current of any liquid is a function of the velocity. Knowing the velocity of a current of water, for instance, we can determine the size of the particles removed by it, and constructing an apparatus in which a sample of clay or soil is subjected to washing by an upward current of water, by starting with a given low velocity we can remove the fine grains, clay substance and dust completely, so that with this velocity after awhile the flowing water is perfectly clear. If, now, the velocity is increased the larger particles will be carried off, and so on.

The law governing this separation is governed by Newton's law of gravity and is modified as follows:

$$d = v^2 \frac{3z}{4g(s-1)}$$

Where d is the diameter of the particle, assuming that all grains are spherical, v the velocity of the water current, g the acceleration of gravity, 9.81 m, s the specific gravity of the particle and z a constant depending upon the surface conditions, its mean value being 2.65. The expression, by substituting the above values, becomes:

$$d = v^2 0.0000255 \text{ millimeters.}$$

This formula assumes that all particles are of equal hydraulic value and that they are spheres of uniform diameter.

The result of many analyses have shown that the above formula must be corrected to

$$d = v^{7/11} \times 0.0314 \text{ millimeters.}$$

in order to correspond to actual conditions. This agrees very well with the results obtained for all velocities between 0.1 mm. and 12 mm. per second, which corresponds to the ordinary clay and silt elutriation.

The apparatus which is used to carry out this method of separation has probably first been used on an extensive scale by Noebel. But considerable improvements have later been made by Dietrich, Masure, Schoene and Mayer. A good method of working and a very satisfactory apparatus have been worked out by Mayer, who improved the Schoene silt apparatus.

But all of these methods, though extremely useful for exact separations, are too elaborate to be used in daily routine of a cement works laboratory, and hence cannot be discussed here in detail. There can be no doubt that the method of moving liquid is more accurate than the subsidence method. For most rigid scientific accuracy the Hilgard method using a perfectly cylindrical funnel and a mechanical stirrer is considered the best. Yet the fact remains that for all around simplicity and rapidity of working the subsidence method must remain the one most satisfactory.

SPECIAL ANALYTICAL AND PHYSICAL PROBLEMS CONNECTED WITH CEMENT ANALYSIS.

Among the problems of indirect importance to the practical cement manufacturer, but of theoretical interest to the chemist, are such problems as the amount of free lime in cement, the amount of chemically combined water in hardened cement, the amount of ferrous and ferric iron present, the condition of the sulphur in the clinker, whether sulphide or sulphate, the degree of absorption of sulphur from the fire gases, the alkalinity of different cements, the melting points of cement and cement mixtures, the effect of the composition and rapidity of cooling upon the crystallization, the heats of solution and hydration and many other problems.

Briefly considering these various problems, we find that the question most profoundly interesting cement technologists has been the query as to the amount of free lime present in cement. This problem has been attacked from all sides, and with practically no results. Thus Liamin, a Russian investigator, endeavored to determine the amount of free lime by calculations from the amount of water given off at different temperatures. Tomei based his work on the action of ammonium chloride on Portland cement, while Hauenschild used other solutions of ammonium salts. Rebuffat made use of a sugar solution, while Zulkowski used a very dilute acid solution. Steuer allowed hydrogen sulphide to act upon water in which Portland cement had been poured; Wormser and Spanjer made use of an alcoholic solution of aluminium chloride for leaching out the calcium oxide, while Hart employed a 10 per cent. alcoholic iodine solution. Wagner studied the action of carbon dioxide upon cement heated to a red heat, and finally Passow made use of the fact that heat is evolved when calcium oxide combines with carbon dioxide at a red heat.

Two investigators, Keiser and Forder, endeavored to determine the free lime by estimating the water taken up in the hydration of the cement during the first short interval of the setting, claiming that the calcium oxide is practically all hydrated in a short time, while the calcium silicate requires a much longer time.

The study of the dehydration process of cements has been taken up by a number of investigators like Bauschinger, Rebuffat, Zulkowski, Newberry and the writer, but the result has been far from satisfactory, owing to the physical conditions which interfered with accurate work. However, by using suitable precautions and refinements of operation, there is no reason why accurate and consistent determinations should not be made. The main difficulty so far has been the density of the test pieces, which on the one hand did not permit of complete hydration, and on the other hindered the expulsion of the water of hydration.

The condition of the iron in cements has been one of the points in dispute, but numerous determinations made have shown that the iron is principally in the ferric condition. This investigation is an interesting one and should be more thoroughly worked out for American cements. Three students in the laboratory of the writer in examining three standard American cements burnt in the rotary kiln found likewise most of the iron in the ferric condition.

Of practical as well as theoretical interest is the question of the sulphur in cements, the changes it undergoes in the burning process and the rapidity with which the sulphur of the fire gases is taken up by the basic cement mixture.

Theoretical experiments as to the alkalinity of cements might prove to be of interest and might be carried on along lines similar to the work of W. Richter, who, for instance, found that well burnt properly proportioned cements do not react with phenol phthalein.

On the physical side, much work remains yet to be done. Some important physical constants of the cement constituents are still lacking, such as the determinations of the melting points, the heats of solution and hydration, and the microscopic study of the principal minerals in the cement slag has not been carried as far forward as should be done. Since the advent of practical electrical furnaces for high temperatures no insurmountable difficulties stand in the way of such research.

In closing the subject of the chemical and physical examination of Portland cement materials a few words may not be out of place in regard to the status of the American cement chemist. There is a more or less well defined tendency in American cement plants to slight the position of chemist by the paying of insufficient salaries, and hence the places are sometimes filled by men with very little technical training beyond the routine of the analytical work. As a result, we find some brands of cement on the market varying to a degree which is inexcusable and which should seriously impair the reputation of the brand on the

market. The most important position around a cement plant is often filled by a poorly paid man, who is not capable of doing the best work which can be done in his line. The works, however, are in charge of a well paid mechanical engineer, often entirely ignorant of the chemical principles underlying cement manufacture. The chemist is relegated to his laboratory where he has little voice in the management of mill affairs, although on him rests the chief responsibility for the quality of the cement. This state of affairs is partly the fault of the chemist and largely the fault of his college training. The usual academic course in a college, with a little elective work in chemistry, does not fit a man for a responsible industrial position, nor does even a good course in pure chemistry. The training of an industrial chemist should be stronger along engineering lines than it is now, with enough work in chemistry to give him clear conceptions of the entire field of chemistry. This can be done in four years, although five years' training would be much more desirable, in spite of what has been said by prominent teachers in chemistry who seem to think that all the time should be spent in studying pure chemistry. Practical experience has shown the writer that the pedagogical value of the study of chemistry is greatly enhanced if supplemented by the study of engineering subjects in an elaborate course of industrial chemistry. Greater mental accuracy is attained and broader conceptions. The subject of industrial chemistry cannot be properly taught except by men who have had at least several years of practical experience in the industries. The teaching of purely college men will invariably lack force and life in industrial topics. As a rule, the average course in industrial chemistry is more or less of a farce, and does not bring out the main principles of combustion, ignition, drying, crushing, grinding, screening, and separating, filtration, etc., with sufficient clearness. But even though the chemical part of the work is unsatisfactory, if the course as a whole contains sufficient general engineering, it will tend to produce men more valuable to the industry. What the American Portland cement industry chiefly needs is well-trained chemical engineers to take the place of the mechanical engineers who are now trying to manage an industry for which their training has not prepared them.

CHAPTER IV.

MANUFACTURE OF POZZUOLANE AND NATURAL CEMENTS.

POZZUOLANE CEMENTS.

Owing to the comparative unimportance of the true pozzuolane cements, but little attention can be given this subject. The preparation of pozzuolane cement is extremely simple and may be carried out in two ways:

- 1st. Grinding of pozzuolane rock together with dry calcium hydrate.
- 2nd. Grinding of pozzuolane alone and mixing it with slaked lime in the wet when used.

Cement made in the first way is, of course, ready for use, and in building need only be mixed with water and sand to be available as mortar. The lime used should be thoroughly slaked and must be dry. When prepared by the second process, care must also be taken to use thoroughly slaked lime. In Europe the second practice prevails, although some authorities urge the preparation of pozzuolane mortar on a large manufacturing scale by the first method. R. Feret advocates the grinding of pozzuolanes as producing a more uniform and satisfactory material. In some places, as in the construction of the Kaiser Wilhelm ship canal, the pozzuolane, which was trass, was ground together with the lime at the works under construction.

Tetmayer has done considerable work with natural pozzuolanes and from his many results the following figures are quoted:

Trass No.	Proportions by Weight.			Tensile strength in pounds per square inch.			
	Trass.	Lime.	Sand.	28 days.	84 days.	1 year.	2 years.
1... {	0.66 0.66	0.33 0.33	3.00 1.00	142.8 158.2	240.8 317.8	249.2 280.0	253.4 291.2
2... {	0.66 0.66	0.33 0.33	3.00 1.00	239.4 187.6	343.0 264.6	309.4 319.2	316.4 351.4
3... {	0.66 0.66	0.33 0.33	3.00 1.00	65.8 81.2	124.6 170.8	207.2 161.8	240.8 320.6

As has already been indicated, the importance of natural pozzuolanes consists principally in the fact that when added to Portland cement they improve the resisting quality of the latter, especially against the action of sea water; but pozzuolane mortar alone, owing to its porosity, is poorly suited for sea water work, and could not be used with any degree of success. The experiments in regard to the benefit of pozzuolane additions are, however, by no means completed.

In some districts along the Rhine and in many localities in Italy the pozzuolanes are simply screened and made up with lime like ordinary sand, this method being quite satisfactory for ordinary work. In the building of Austrian railways the proportion of 1 part lime to 3 parts pozzuolane was found to be the best.

SLAG CEMENT.

General Considerations.—When fused basic blast furnace slag of the composition already indicated in the chapter on "Raw Materials" is suddenly quenched in water, the rate of cooling is, of course, the most rapid possible. If, as is generally assumed, slow cooling is associated with the breaking down or dissociation of complex mineral compounds into simpler ones it is evident that the quenched slag is not given a chance to do this. It must, of necessity, remain the complex glass it was when in fusion. This granulated slag on being mixed with lime produces, as we know, a hydraulic cement of considerable strength. Yet the same slag cooled slowly shows but little hydraulic strength. We are evidently in this instance dealing with a far-reaching molecular change.

Work of Zulkowski.—The first to realize that he was dealing here with isomeric compounds and to scientifically investigate these was Professor Zulkowski, of the University of Prague.* Though his work has been considerably criticised, it must be acknowledged that it brings out fundamental principles which cannot be ignored. They bear important relations to the general question of hydraulicity whether referring to slag or to Portland cement.

Glass, an amorphous mixture of silicates, or a solution, as we may call it, when heated for some time at a low temperature, will be found to crystallize, as we can observe when the glass combustion-tube used in chemical work assumes a porcelain-like appearance after long use. On examination these crystals have been found to be the simple monocalcium silicate, wollastonite. All slags, whether basic or acid, may likewise be called glasses with the same tendency to crystallize on slow cooling. In recent experiments** definite minerals have been recognized as uniformly appearing in all basic slags, some of them predominating in strongly hydraulic and others in feebly hydraulic slag. And it is of

**Die Chemische Industrie*, 1889, p. 69.

***Dr. Passow, Stahl und Eisen*, Aug. 1st, 1903.

special interest to note that some of these minerals are identical with those found in Portland cement. Five of these minerals have been found. The principal ones are:

1st. A white crystalline mineral, high in lime, called alite, found in rapidly cooled basic hydraulic slags, and all Portland cements.

2nd. A double refracting mineral showing distinct parallel striations found in all slags and cements of inferior hydraulic value and showing a tendency to fall to a powder. This is called felite.

3rd. A glassy, usually dark-colored mass of good hydraulic value, in fact being equal to the alite in cementing quality. Of course, only the glass-like mass appearing in basic slags, and Portland cements, is meant here. The glassy constituent which predominates in acid slags has no hydraulic properties. Quenched basic slags show this glassy component in predominating quantity.

Zulkowski assumed that the hydraulic mineral varieties of basic slags are preserved only by rapid cooling, while on slow cooling they break down to simpler non-hydraulic compounds. This agrees very well with practical results, inasmuch as we know that frequently Portland cement mixtures produce excellent cements when burnt rapidly, but "dust" or form a slightly hydraulic powder when burnt slowly. This cement producing constituent, whether found in slags or Portland cements, Zulkowski called "hydrolite," which as we now know consists essentially of alite or cement glass, or both.

By treatment with dilute acid Zulkowski endeavored to separate the constituents of the slowly and rapidly cooled slags which, of course, is a crude and unsatisfactory procedure, and his earlier results based on this work deserve little attention. But he brought out the very interesting fact that quenched basic slag, though possessing cement qualities, brings out its inherent maximum hydraulic value only when mixed with a small percentage of slaked lime. Zulkowski now looked into this question by treating granulated slag not only with lime, but also with strontium, barium, and alkalies. All of these showed the same behavior, and caused the slag to become a good cement. It was also found that the compound thus added did not combine chemically with the slag itself. Thus, for instance, the alkalies could be washed out from the hardened cement after they had caused the slag to harden. Water alone evidently is the reacting substance in uniting with the hydrolite to form a hydrous silicate. Caustic lime simply accelerates and assists this absorption. Very basic slags do not need an addition of lime. Having arrived at this conclusion, Zulkowski at once was able to trace the analogy between slag and Portland cement by saying that the latter consists of the same hydrolite as the slag cement plus free lime. Portland cement, therefore, like very basic slag, does not need an addition of lime.

On experimenting with the slag, which alone hardens slowly in water, it was found by means of the microscope that it consisted of small glitter-

ing grains like pulverized glass. On adding water to 20 grams of the ground slag, the sandy portion settled first and then a heavy flocculent mass was precipitated. At the same time the volume of the powder constantly increased until it was about twice the original volume. The appearance of this hardened powder did not differ essentially from that of the dry slag. But this action is much more energetic if alkalies, barium, or lime water is added. The volume becomes three to five times the original volume, and assumes the colloid character. The mass hardens very rapidly, and the small grains of slag change to swollen, rounded particles.

The conclusions of Zulkowski may be summarized as follows:

1. The blast furnace slags, suitable for the manufacture of cement, are highly basic meta-silicates whose decomposition is prevented by rapid cooling or granulation.

2. Owing to their anhydrous condition, they have a tendency to unite with water and to harden, which is assisted by the presence of alkalies. Such silicates may be called hydrolites.

3. On slow cooling, an inter-molecular decomposition of the meta-silicate or hydrolite takes place in a greater or smaller measure. During this process the mass loses its uniformity, and the constituents are not dissolved by weak acetic acid in the proportion in which they are present in the slag.

4. The hydration of the powdered basic meta-silicate is coincident with a change in volume, and a change in the shape of the grains, which now fill all the space, and gradually harden to a compact mass.

5. Slags cooled slowly, which contain only certain components or isomeric compounds of the above meta-silicates, do not possess the properties of the hydrolite, mentioned under 2 and 4.

6. Portland cement, like slag cement, is a mixture of a hydrolite analogous to granulated furnace slag, and as much lime as remained uncombined on burning. The difference between the two is only that the necessary lime must be added to the slag in the shape of calcium hydrate.

7. The calcium oxide of Portland cannot be separated directly.

8. The calcium oxide may, however, be removed from Portland cement by a special treatment with dilute hydrochloric acid in greater or smaller amounts, and the hydraulic property is diminished accordingly. The residue remaining behaves like highly basic slag; that is, it hardens in the presence of the alkaline compounds without combining with them chemically.

9. But since the calcium oxide is thus removed in the wet way, the cement is sufficiently hydrated and the residual cement can never attain its original strength. The hydraulic agent of Zulkowski is represented by the structural formula, Fig. 14, which hydrates to Fig. 15.

This formula is thus seen to be deduced from a basic meta-silicate which hydrates by the taking up of a molecule of water.

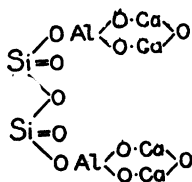


Fig. 14. Zulkowski's formula for hydrollite. before hydration.

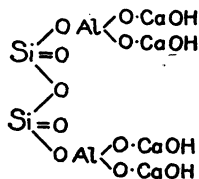


Fig. 15. The same after hydration.

Chatelier arrives at different conclusions by assuming that the granulated slags combined with lime are rendered chemically active by retaining the latent heat otherwise given off in crystallization. Prost has investigated this point and has really found that crystalline (slowly cooled) slag on dissolving in hydrochloric acid evolved 301 calories, while the granulated slag gave off 420 calories.

Selection and Granulation of Slags.—The limits of composition have already been given by the values established by Tetmayer, and it might be said that the more basic the slag, the better suited it is for cement making. The slags especially suitable for this purpose show from 27 to 32 per cent. silica, 10 to 22 per cent. alumina, 48 to 56 per cent. lime, 1 to 2 per cent. magnesia. The sulphur content should be carefully watched and never allowed to run above 1.25 per cent.

It is of the greatest importance to reject any slag not suitable for cement making and to make use of it in connection with the manufacture of slag brick, for which purpose the slag may be of inferior quality, that is, much less basic. In this manner it is possible to maintain a higher grade of excellence without financial loss. It is advisable therefore to have a slag brick outfit in connection with a slag cement plant. The fitness of a slag is determined by chemical analysis, which must be supplemented by physical tests; the dried granulated slag must be ground together with varying proportions of dry slaked lime, usually from 5 to 15 per cent., and tested for tensile strength and constancy of volume as prescribed by the standard cement specifications.

The granulation may be carried out in two ways: by means of a stream of water or by means of a blast of air. There is no question but that the first method is the more satisfactory one, resulting in the best quality of granulated slag, but it has the disadvantage of producing a wet slag which must be dried. The amount of water retained by the slag is not great, however, and hence the extra cost of manufacture is not an important factor. Some theoretical advantages, on the other hand, are claimed for the air cooled slag, but these are not proved sufficiently by actual results. The slag is granulated by means of a flat

stream of water about 6 inches wide under as great a pressure as possible. In one case known to the writer the water is under a pressure corresponding to a 70 foot water column. The effect upon the molecular structure of a slag by granulating it by means of water has already been discussed. Practically the effect is extremely marked. A French engineer, H. Detienne, has approached the point from the practical standpoint, by grinding granulated and ungranulated slag together with equal amounts of hydrated lime. The cements thus produced were made up with standard sand in the proportion of 1 part of cement to 3 parts of sand, and tested for tensile strength. After 28 days the ungranulated mixture showed a tensile strength of 60.2 pounds per square inch, while the granulated slag mortar indicated 126 pounds. Tetmayer found much greater differences owing probably to the fact that Detienne used samples of slag cooled rapidly in the air and also did not grind his cement very fine.

The water used in granulation probably does not enter into combination with the slag to any extent, and the only change is the removal of part of the sulphur of the slag, going off as hydrogen and calcium sulphides. Granulation of the semi-solidified slag has but little effect on its hydraulic value.

Drying.—The granulated slag, after its excess of water has been allowed to drain off, is conveyed to the dryer; a rotary dryer 30 feet long and 5 feet in diameter, fired either with gas, crude oil, or coal is the most satisfactory. It has often been asked how slags too high in sulphur might be improved by the complete or partial elimination of this injurious ingredient, and it has been proposed to carry on this refining process during the drying operation. But as yet no definite or satisfactory scheme has been worked out. The use of steam and carbon dioxide has been suggested and some work has been done along this line. It seems that the use of steam offers a promising process, since it has been shown that the calcium sulphide is to a large extent decomposed by it. If, however, saturated steam is to be used, it is evident that this treatment must precede the drying owing to the condensation of steam. If, on the other hand, superheated steam is used, which also is the more efficient, the two processes could be combined. The dryer would have to be made much longer in this case, as long as a rotary kiln, 60 feet. By introducing the steam at a distance of, say, 20 feet from the discharge end of the apparatus and the hot gases from the coal fire, gas jet, or oil burner at the lower end as usual, condensation at the discharge end would be avoided entirely. The temperature of the steam should not fall below 300° C. In this connection it might be stated that the sulphur present as calcium sulphate evidently can not be expelled by this procedure. By maintaining reducing conditions of the fire gases, the expulsion of sulphur should be assisted most decidedly, especially if the temperature ap-

proaches red heat. However, the whole scheme, as has been said before, needs to be tested on a large scale before it can be pronounced commercially feasible.

Intermediate Grinding.—From the dryer the slag is conveyed to iron cooling bins, and then to the intermediate grinding machinery, that is, machines which grind sufficiently fine so that the bulk of the material passes the 20 mesh sieve. These machines may be ball-mills, disintegrators, Kent mills, rolls, dry-pans or buhr mills. We cannot discuss the relative merits of these machines here, since it will be necessary to study them more in detail in the chapter devoted to Portland cement, but it may be said that the machines more commonly employed are the ball-mill, the disintegrator and the Kent mill. Each of these machines will do the work satisfactorily. Although they may differ in efficiency, these differences are not very pronounced with material like granulated slag.

The roll crusher, as far as cheapness of operation is concerned, is more efficient than any of the three preceding machines, but, probably owing to its aptness to choke when overcrowded, the unequal wear and the small amount of fine material it turns out, it has not found as general application as this system really deserves.

The drypan, although a machine of great capacity, occupies much room and does not do as uniform grinding.

As to the buhr mill, it must be classified as a wasteful machine, in regard to power consumption, besides requiring constant attention owing to the dressing of the stones. A higher claim of efficiency can be made for the emery mills in which the latter item is reduced considerably.

The Lime.—After leaving the intermediate grinding machine, the slag is taken to a bin in order to be delivered to the fine grinding machines. At this stage the hydrated lime is added.

The amount of lime to be added varies, and must be determined for each individual slag, by grinding the dried granulated slag together with varying amounts of dry, slaked lime, and applying the various cement tests. In the majority of cases the addition of lime necessary will fluctuate between 5 and 15 per cent., being usually closer to 5 than to 15 per cent. The lime is ordinarily bought as quicklime, and is slaked at the cement works, though of course a considerable saving might be effected by burning it at the plant, since limestone is invariably shipped to blast furnaces to be used as flux, and never comes a great distance. As to the burning, it could be accomplished in an ordinary limekiln, operated continuously, using coal or blast furnace gas as fuel. The lime should be as low in clay and free silica as possible in order that it may slake freely and not give rise to hard lumps which slake slowly and give trouble when ground with cement. Such slowly slaking lime, though finely ground, will invariably cause difficulties owing to its increase in volume when the

cement itself has set to a hard mass, giving rise, of course, to cracking or swelling.

Methods of Preparation of the Lime.—Although slaked lime can now be purchased on the market, it will usually be found too expensive. Slaking may be carried on: first, by the old pile slaking; second, by the periodic cylinder method; third, by the continuous slaking machine. In the ordinary pile slaking a heap of quicklime is made, as much water sprinkled over it as practice has shown to be necessary, and allowed to slake for some time. The slaked lime is then put through a 10 mesh screen, which may either be a long stationary inclined screen or a mechanically driven rotary sieve. It is obvious that too much water will have the effect of producing a moist hydrate which cannot be screened, and hence the addition of water must be carefully gaged. The screened lime is now taken to a cast iron pan, about 15 feet long, 8 feet wide, and 12 inches deep, kept heated by means of a furnace beneath. When dry, the slaked lime is scraped from the pan and put through a 20 mesh screen. By means of a conveyor, the hydrated lime is taken to the bin ready to be used.

In the cylinder method of slaking a large quantity of quicklime, say one ton, is dumped into a steel cylinder provided with a large manhole and swung on trunnions. The manhole is then closed and through a pipe the requisite amount of water is introduced. The heat given off by the hydration soon converts the excess of water into steam under a great pressure. A safety valve must be provided to relieve any excessive pressure. Slaking thus takes place under pressure, and the slaked lime is in the condition of a powder. It has also been proposed to revolve the cylinder in order to accelerate the slaking. After the slaking is completed, the cylinder is placed in position with manhole down and the lime dumped into suitable receptacles.

In the third method, which has so far not been worked out on a practical scale to the writer's knowledge, but which has the great advantage of continuous operation, three stages are to be noted. The first part of the process, the slaking, is carried on in long, tubelike cylinders, about twelve feet in length, somewhat similar to a clay pugmill, in which two shafts provided with blades revolve rapidly. At the feed end where the quicklime is brought in as powder, water is sprayed in under pressure, somewhat in excess of the amount required, which must be, of course, gaged by an attendant. The rapidly revolving knives or blades bring about thorough blending of the lime with water. At the discharge end of the machine, the hydrated lime is taken to a large sheet iron bin, of such dimensions that the lime is allowed to remain in it for two or three hours. At the bottom of this bin a revolving feeder is arranged which feeds the slaked lime into a rotary dryer in which the material is dried by a current

of hot air, produced by passing the air through an iron coil heated by a furnace. The dried lime is then run through a disintegrator and again converted into powder. This method, being continuous, evidently must result in a much greater capacity than could be attained by either of the other methods.

The Addition of the Lime.—The lime hydrate, whatever may be its preparation, is added to the granulated slag coming from the intermediate grinding machine and now stored in a bin above the fine grinder. The mixture may be accomplished by a mechanical feeder, consisting of an iron disc revolving beneath both the slag and the lime bin, so that both materials are fed upon it, the slag through an aperture whose area is to the area of the lime feed hole as the proportion of slag is to that of the lime necessary. It is evident, of course, that both of the apertures must be adjustable. As the disc revolves, a scraper turns off the two materials into the screw conveyor, feeding the fine grinding machines. Another device observed at an Ohio slag cement plant was a flat slider similar to an engine slide valve having a reciprocating motion and moving beneath the slag and the lime bin. It had two sets of holes, large ones for the slag, and smaller ones for the lime. With each stroke of the slide, a quantity of slag and lime was allowed to fall through these holes for a short interval of time. In some plants the slag and lime are weighed out by means of scale cars and dumped into a small bin feeding the fine grinders.

Fine Grinding.—As fine grinders, there are two machines to be considered principally; the tube mill and the Griffin mill. The former is a machine resembling a tube, from 18 to 22 feet in length and about 5 feet in diameter, into which the slag is fed and from which it is discharged continually. The grinding is done by means of flint pebbles filling the machine to slightly above the axis. Beside the grinding action proper, this machine affords a splendid blending of materials approaching almost ideal mixing. At the same time it eliminates the use of all screens, the required fineness being obtained by the rate of feeding. On the other hand it consumes much power.

The Griffin mill might be compared with a mortar and pestle, since it consists of a revolving conical pestle weighing about 100 pounds, and about 18 inches in circumference, suspended from a universal bearing. When in motion the pestle is pressed against a steel ring by centrifugal force and thus effects the grinding. This ring is about 6 inches high and a little over 30 inches in diameter. The pestle itself revolves about its own axis, thus rolling against the surface of the ring. By means of fan blades, above and below the cone the fine particles produced are blown through screens surrounding the grinding space.

There are several other mills on the market similar in principle to the Griffin mill, like the Huntington mill, the double pendulum mill using two rolls in place of the one of the Griffin mill, and others.

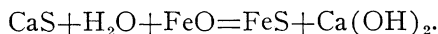
As far as the grinding proper is concerned the efficiency of these mills is undoubtedly higher than that of the tube mill, but owing to the factor of centrifugal force they do not accomplish the thorough blending of the former. In fact since the expression for the centrifugal force

$$C = \frac{Wv^2}{gR}$$

involves the factor of the mass of the particles it is readily seen that there must be a tendency to segregation of unlike particles of different sizes and weights. In the manufacture of slag cement we blend two materials, slag and calcium hydrate, having the specific gravities 2.8 and 2.1 respectively, and it seems quite evident that the blending accomplished by the Griffin mill is bound to be inferior in quality as compared with the work of the tube mill.

From the fine grinding machine the ground slag cement is conveyed to the storage bins and is ready for shipment, since it is not necessary to "cure" slag cement as is the case with Portland cement.

Testing of Slag Cements. —In first bringing out a slag cement, it is of great importance to subject it to the most rigid tests known to the manufacturer in order to determine, as far as it is possible to do so, its properties and ultimate behavior in use. The tests employed are the same to which Portland cements are subjected, special attention being paid, however, to the tests for constancy in volume. Finely ground slag cement of the proper composition, containing not more than 1.3 per cent. of sulphur and 3 per cent. of magnesia will, as a rule, produce a sound cement. A peculiar color phenomenon is noticed in the hardening of slag cements in water, the change of the first bluish gray color to a pronounced green color, which, however, disappears in time. This is probably due to the reaction:



The sulphide gradually changes to calcium sulphate which, owing to its solubility, is brought to surface by water and appears as a white efflorescence. The remaining calcium sulphide also oxidizes to calcium sulphate, forming crystals in the interior. This salt plays an important function as regards the durability of the cement, since on oxidation it suffers a decided increase in volume which tends to break up the hard mass of the cement. In water this effect of crystallization is less apparent, and hence all slag cements, especially those high in sulphur, are at a disadvantage when hardening in air or exposed to it after hardening, and show their best strength only in work under water, foundations, etc. They are unsuited for work exposed entirely to the air like in sidewalks.

Another disadvantage is the tendency to effloresce, made mention of above. On the other hand it has been claimed that in sea water construction and all other subaqueous work, slag cement appears exceedingly well; in fact, some claim for it superiority over Portland cement. Altogether, the slag cement is a hydraulic mortar par excellence. But it cannot be denied that its weak side is the tendency to shrink during the setting stage, so that it must be protected carefully against too rapid drying, and must have plenty of water in order to bring about the complete formation of the colloid hydrous silicates which are the cementing agent. This tendency to shrink or crack is proportional to the content of calcium hydrate, hence it is plain that the content of the latter must be kept as low as possible.

Tetmayer found on preparing cements from mixtures consisting of 100 parts of slag and 20 parts of slaked lime, 100 slag and 40 lime, 100 slag and 60 lime, 100 slag and 80 lime, and making them up into cubes of 7 cm. face, that after 28 days the linear shrinkages were in the above order: 0.034, 0.060, 0.085, and 0.132 mm.

If slag cement fails in the cold and hot tests for constancy of volume, this is almost invariably due to the imperfect grinding of the lime, or the slow slaking character of the latter, or poor slaking or excess of sulphur.

Slag Cement in Ohio.—So for the only plants in Ohio producing slag cement are the Brier Hill Coal & Iron Company, Youngstown, and the Strouthers Furnace Co., Strouthers, but there is no reason why the manufacture could not be carried on by other blast furnaces of the State.

A test of the Youngstown material gave the following results:

	Per Cents.
Silica.....	28.20
Alumina and iron.....	11.60
Lime.....	52.80
Magnesia.....	2.37
Volatile matter.....	2.75
Sulphur.....	1.57
Total.....	99.29

It left approximately 3.8 per cent. on a 200 mesh sieve. The initial set was 1 hour and 20 minutes; the final set 3 hours and 10 minutes. It stood both the hot and cold test. The tensile strength was as given in table on top of page 169.

Hatt's Results. —Wm. Kendrick Hatt* made extensive examinations of American slag cements which are summarized in second table on page 169.

**Engineering Record*, Vol. 43, No. 9.

Tensile Strength in Pounds Per Square Inch.

Age.	Neat.	1 Cement : 3 Sand.
24 hours	330	75
7 days	502	223
14 "	610	310
21 "	545	322
28 "	715	348
3 months	655	340
6 "	728	340
1 year	758	343
2 years	768	408

Table of Chemical Analyses of Slag Cements Examined.

Cement.	A	B	C	D	E
Lime.....	55.85	63.50	56.55	54.75	53.30
Silica.....	28.81	19.46	27.48	29.50	20.08
Alumina and iron oxide.	10.74	10.94	10.86	11.02	10.80
Magnesia.....	1.28	2.08	1.75	1.44	3.44
Sulphur as Sulphide....	0.35	.....	0.43	0.30	0.47
Sulphur as Sulphate....	trace	0.35	trace	trace	1.36
Loss on ignition.....	2.31	1.22	3.41	2.73	2.63

Cement E is really not a slag cement, but is made from slag, like Portland cement.

Average of the Tensile Strengths Obtained by Breaking Six
Briquettes of Each of the Preceding Five Cements.
Pounds Per Square Inch.

Age.	Neat.	1 : 1	1 : 3
24 hours	193	144	39
7 days	404	390	163
28 days	477	403	174
60 days	519	498	208
90 days	507	483	217

Crushing Strength Tests, in Pounds Per Square Inch.

Cement mixture.	A		B		C	
	In air.	In water.	In air.	In water.	In air.	In water.
Neat	2,724	2,433	2,555	1,871	3,687	3,216
1 : 1	2,168	2,153	2,445	2,314	6,468	2,816
1 : 3	667	553	748	317	810	727

Addition of Portland Cement to Slag.—It has become quite a practice in Europe to add Portland cement to granulated slag in place of the slaked lime, since this addition produces a much better product, less sensitive to rapid drying conditions in setting and of a much higher all around strength, besides eliminating the troublesome slaking and handling of the lime. The Portland cement is either bought or made from the slag at hand, mixed and ground together with limestone in the proper Portland cement proportion. Such a mixture of granulated slag is called by the Portland cement manufacturers an adulterated Portland cement and not without justice. It must be evident that such a cement should never be sold under the name of Portland cement, but should be given a distinctive name, clearly indicating its character. If the cement cannot stand upon its own merits, it should not attempt to borrow credit from the Portland cement. In Europe this product is called "Iron Portland Cement."

Dr. Passow has investigated the effect of adding Portland cement to the granulated slag and has obtained the following results. All tests are 1:3 standard sand mixtures and have been made after 28 days.

Mixture.	Tensile strength in pounds per square inch.
Portland cement (1 : 3)	327.1
77% Portland cement + 23% granulated slag (1 : 3).....	448.0
54% Portland cement + 46% granulated slag (1 : 3).....	484.9
Portland cement + 30% fine ground sand(1 : 3).....	301.5

These tests all show plainly that the granulated slag does not play the role of a mere inert substance like sand, but effects a decided increase in tensile strength.

It cannot be questioned that the addition of Portland cement furnishes an ideal substitute for the slaked lime, and there enters into consideration

only the question of cost. It would hardly pay to purchase Portland cement on the market for this purpose and it would hence be necessary to produce it at the works, which could be done without any practical difficulty by using slag and limestone. But, on the other hand, the question arises: Why not make Portland cement altogether from the slag available, and thus eliminate the peculiarities of slag cement which requires constant moistness and careful drying though sacrificing the increase in tensile strength obtainable by the use of slag? This question cannot as yet be answered definitely, as we do not know the properties of the Portland-slag cement very thoroughly. If this cement can fill the requirements put to Portland cement, there is no reason why it should not compete with the latter. If it cannot, its manufacture must be governed by the market conditions and it should be sold only for purposes for which it is entirely suitable, viz., underground or subaqueous work. The present indications are that the "Iron Portland" cement is suitable for much work in which the standard Portland cement is employed, but this cannot be accepted as being established. Until proven otherwise, all slag cements and mixtures must be considered inferior to Portland cement with regard to all around usefulness. But recent European evidence brings out much in favor of the Iron Portland cement.

Summarizing, we have these two kinds of processes which utilize slag:

First, manufacturing slag cement, using slaked lime, and converting all unsuitable slag into slag bricks.

Second, manufacturing Iron Portland cement, using the inferior grades of slag for producing the Portland cement necessary in this process, since in this way it can be corrected, if defective in composition, by the addition of limestone. Either process provides for any unsuitable slag and hence eliminates waste. The diagrams on pages 172 and 174 indicate in a general way the arrangement of these two types of plants.

Slag Brick.—These, made from a mixture of granulated slag, slaked lime and crushed, hard slag in various proportions, from 75 parts of granulated slag, 8 per cent. of slaked lime and 17 of hard slag down to 30 parts of granulated slag, 3 parts of slaked lime and 67 parts of hard slag, are being made in large quantities and have proven entirely suitable as far as strength is concerned, as they show crushing strengths far beyond the requirements. Their chief drawback is in the undesirable gray color and the tendency to "whitewash" owing to the presence of the sulphur salts. The manufacture is extremely simple, consisting of grinding both the granulated and hard slag to a fineness between about ten and twenty mesh sieve, mixing the two kinds of slag with the slaked lime in a mixer of the pug mill type, moistening the mixture till damp and

A - SLAG CEMENT & SLAG BRICK PLANT

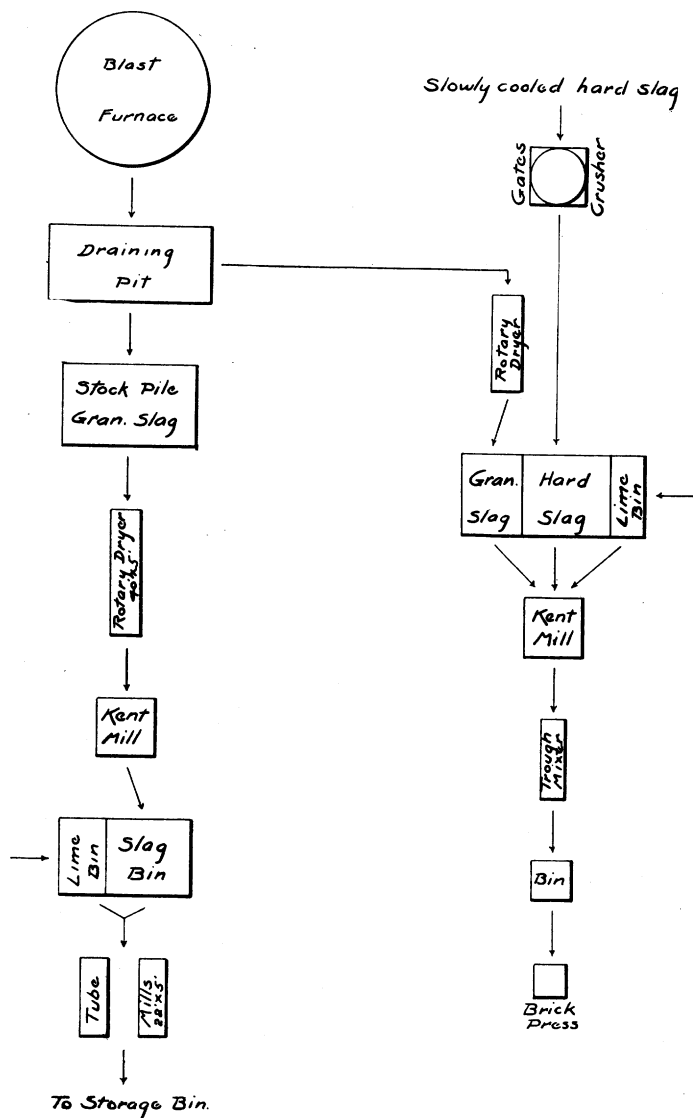


Fig. 16. Ground plan of a plant for manufacture of slag cement, the unsuitable slag being converted into slag brick.

finally pressing the material into bricks by means of a press similar to the dry presses used in clay brick making. The capacity of the largest machine of this kind is about 20,000 bricks per day. In selecting a press for this work care should be taken to see that its plungers are provided with carefully adjusted powerful springs in order that, in pressing, the plungers will give some whenever an excess of material happens to be fed by the charger, thus preventing breaking of the machine. It is hardly necessary to say that the press should be of the heaviest possible construction. In Europe a press is used in which the pressure is applied by a heavy plunger falling freely upon the material in the mold, thus doing away with all possible danger of breakage due to an excessive charge. However, the bricks thus made are not as dense as they should be, and are apt to be crumbly. It is important that the top and bottom dies do not fit too tightly in order to allow the enclosed air to escape. The slag brick should not be taken into a dry atmosphere at once, but should be allowed to remain in a moist room for several days. After two weeks they are, as a rule, ready for the market. It is obvious that in making these bricks Portland cement may be added in smaller percentages and may be used as a substitute for the lime.

MANUFACTURE OF NATURAL CEMENT.

This branch of the cement industry is the simplest one and consists solely in taking the rock as it comes from the quarry or mine, in lumps, burning it in plain upright kilns, and grinding the burnt, friable pieces to a powder. No attempt to regulate or control the qualities of the product can be made except by varying the speed of burning, or by using a higher or lower temperature, and hence the burning becomes the most important operation.

The rock is either quarried or mined. In the quarries of the natural cement mills, all modern quarry appliances are used, steam or compressed air drills and power cranes. High explosives are, of course, universally employed.

The treatment of the quarried cement rock differs in different plants. The more progressive mills crush the rock into two or three uniform sizes by means of Blake crushers, while others make no attempt to crush it, but put it into the kiln in the shape in which it comes from the quarry. It is evident that by crushing the rock, greater uniformity of burning must be the result as well as better utilization of the kiln space.

The rock is burnt until most of its carbon dioxide is expelled, and the stone has become very porous, and is quite friable. It is practically unavoidable that some of the stone be underburnt, and some of it overburnt, that is, burnt to a vitrified clinker. It is endeavored to sort out both kinds as much as possible.

The sorted stone is now conveyed by means of cars or barrows to the intermediate crushing machines, usually a machine of the "corn-sheller"

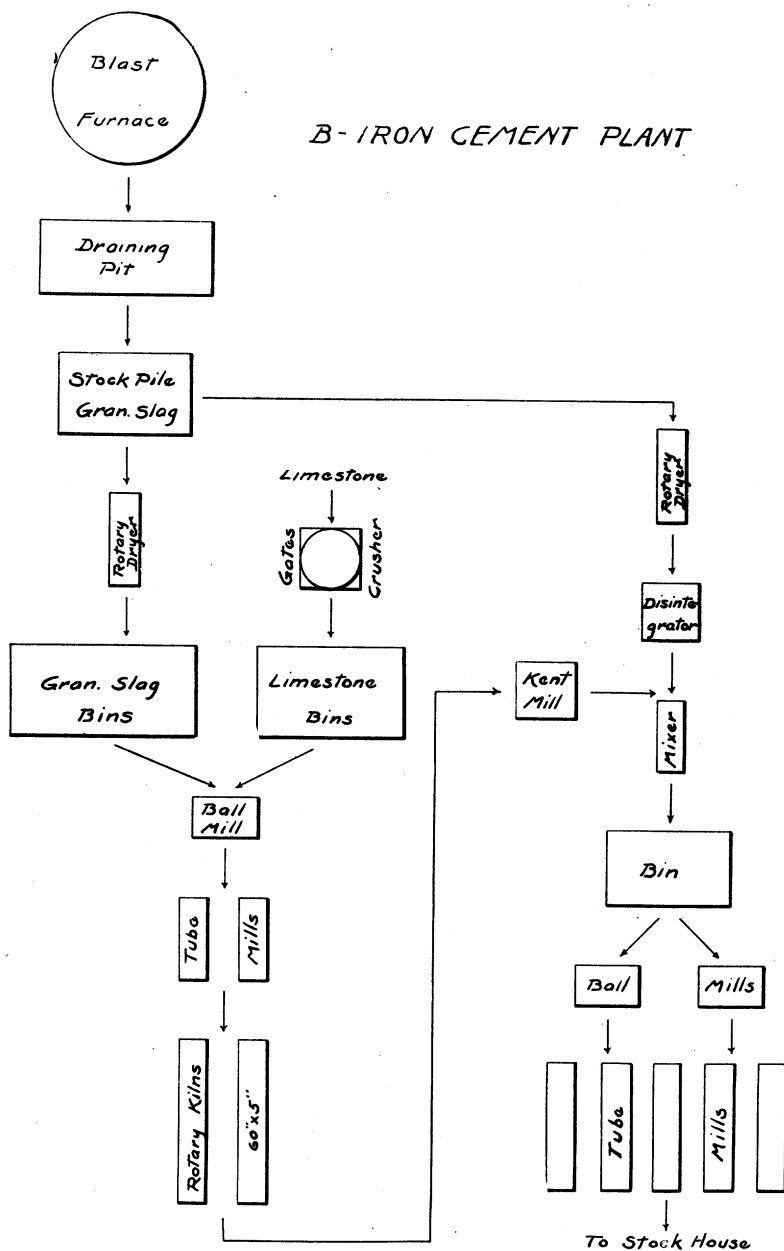


Fig. 17. Ground plan of a plant for the manufacture of "Iron Portland" cement.

type, called a "cracker," which consists essentially of a ribbed, steel-faced or chilled iron cone, revolving within a conical space, the cone being rotated by means of a vertical shaft. From this machine the crushed material is conveyed to screens, which separate the cement which is fine enough to be packed. The coarser particles go on to the fine grinding machines, which in most plants are ordinary mill-stones or emery-faced stones. As a rule the cement is packed at once on coming from the mills.

INVESTIGATIONS ON THE BURNING PROCESS.

We know from the examination of the cement-rock analyses that we must distinguish between calcareous and magnesian rocks, that is, stones high in lime and low in magnesia and those containing more than 5 per cent. of magnesia. The typical Roman cement formula we have found to be: 1.60RO , $0.23\text{Al}_2\text{O}_3$, SiO_2 .

Minerally, we are here dealing with an intimate mixture of carbonates with clay, and mineral detritus of various origin, quartz, hornblende, augite and mica. In burning, the first stage must necessarily be the expulsion of the carbon dioxide; with the production of calcium oxide, the reaction between it and the accessory silicates and silica will begin. It is but natural to suppose that the clay should be attacked first by the calcium oxide, followed by the silicates, and finally by the free silica.

Work of Nauss. —R. W. Nauss investigated this question of the action of calcium oxide on clay and quartz to some extent in his thesis for graduation at the Ohio State University, by making up a mixture of whiting, pure kaolin and quartz (between 120 and 150 mesh) of the following composition in the unburnt condition:

	Per Cents.
Calcium carbonate.....	70.22
Kaolin.....	11.05
Quartz.....	18.66
	99.93

which would correspond in the burnt condition to:

	Per Cents.
Calcium oxide.....	58.45
Alumina.....	6.35
Silica.....	35.30
	100.10

This mixture was made up into briquettes, which were weighed when dry, heated in a kiln to different temperatures, and drawn at intervals above 500°C . The briquettes were then cooled in a dessicator and again weighed. In addition, determinations of the insoluble silica were made by treatment with hydrochloric acid and sodium carbonate solution

and the carbon dioxide was determined approximately by absorption and volumetric measurement. The temperatures were measured by means of the Chatelier pyrometer. In the following table the results obtained by Nauss are compiled.

Reaction of Calcium Oxide upon Kaolin and Quartz.

Number.	Temperature °C.	Loss on burning.	Loss on completed ignition.	Carbon Dioxide remaining	Insoluble silica per cent.	Remark .
1	550	1.79	27.79	28.48	.....	
2	585	1.88	27.96	28.44	.....	
3	610	1.80	28.67	28.84	.....	
4	655	1.91	28.83	27.83	.....	
5	700	4.81	25.17	25.89	.....	
6	725	6.18	24.30	24.58	.....	
7	750	6.99	23.02	23.88	.....	
8	775	8.35	21.90	21.07	19.70	
9	800	12.51	17.94	18.72	.....	
10	850	20.34	10.64	7.32	19.00	
11	900	24.42	5.89	5.29	.....	
12	950	27.56	2.88	2.17	18.90	
13	1,000	30.00	0.60	0.40	18.83	
14	1,050	29.75	.....	.....	18.75	
15	1,100	29.65	.....	.....	18.75	
16	1,150	29.74	.....	.....	18.26	
17	1,150	30.10	.....	.....	16.19	Held at this temperature for 12 hours.
18	1,200	30.10	.....	.....	16.10	
19	1,200	30.10	.....	.....	15.37	
20	1,250	30.10	.....	.....	13.13	Dusted.
21	1,250	30.10	.....	.....	13.34	"
22	1,300	30.10	.....	.....	11.97	"
23	1,300	30.10	.....	.....	10.68	"
24	1,325	30.10	.....	.....	.....	Began to fuse.

The following conclusions may be drawn from Nauss' work:

First. In regard to the decomposition of calcium carbonate, it is clearly shown that it begins to break up between 610° and 650° C., and before 700° is reached the evolution of carbon dioxide is going on quite rapidly. At 1000° the evolution is practically at an end.

Second. On examining the amounts of insoluble residue and comparing the percentage with the known amount of quartz in the mixture, 18.66 per cent., and making allowance for the small amount of quartz in the kaolin itself, it is seen that the kaolin is decomposed completely at 850° C. and almost completely at 800° C.

Third. Free quartz seems to be attacked by the calcium oxide soon after the completion of the decomposition of kaolin, probably at about 950° C., which reaction continues at an increasing rate up to the highest temperature employed in these experiments. It is quite evident, also, that the length of time of burning influences the amount of quartz attacked somewhat, so that by longer burning, at least with temperatures over 1100° , more quartz may be rendered soluble than in a short period of ignition.

A very interesting fact was brought out by the tendency to dust observed with the mixtures burnt at temperatures above 1200° . While at 1200° the briquettes were hard, at 1250° , they dusted very rapidly, and at 1300° almost instantaneously.

On calculating the formula of this mixture from the composition we find it to be 1.77CaO , $0.108\text{Al}_2\text{O}_3$, SiO_2 , that is, not quite a singular calcium silicate, and hence might properly be classed within the group of natural cements. It is not difficult to understand that the dusting must be coincident with a significant molecular change from the condition of the loose, friable mixture to a hard body breaking down at once to a powder. Might not this fact indicate that up to 1200° these calcareous mixtures are but pozzuolane-like, simple silicates, consisting of silicate and free base which on further application of heat become chemically more complex and non- or but slightly hydraulic? This view is strengthened by the results of another investigation which has shown that on increasing the free silica, with but sufficient base to convert the quartz into the active state, the hydraulicity is practically as great as with a greater amount of base.

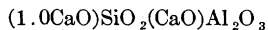
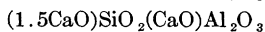
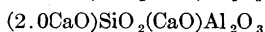
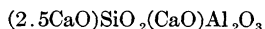
Kennedy's Results.—This subject seems important to the writer, since, evidently, all Portland cement must pass through these reactions, and it is necessary for the proper understanding of the genesis of these cements that we should know something in regard to the initial stages of the formation of the hydrolite.

The expulsion of carbon dioxide from a kaolin-calcium carbonate mixture is pictured rather clearly by the accompanying curve* representing the per cent. of the original weight of briquettes, made up from 70 parts of kaolin and 30 parts of whiting (calcium carbonate) remaining after heating at different temperatures. The time occupied by the experiment was 28 hours. The temperature was increased steadily up to 725°, when this heat was maintained for a little over 12 hours to observe the effect of heat soaking on the briquettes. The temperature was then raised steadily to 1000°. In this curve the interesting fact was brought out that while in pure kaolin the chemical water is expelled between 450° and 600°, the carbon dioxide from the briquettes containing 30 per cent. of the carbonate will prolong the dehydration to 900°. Heat soaking for a comparatively long period is of no advantage, for, though it drives off some additional carbon dioxide, this amount is but small. This agrees with the laws of phase rule.

Investigations Carried on by the Writer.—In order to study further the effect of composition and temperature of burning of the Roman cement type on the resultant hydraulicity the following series was projected and carried out by the writer. Two clay bases were prepared, one consisting of almost pure kaolin and one of a mixture of kaolin and very fine ground quartz, passing a 150 mesh sieve, made up from 56 parts of kaolin, and 44 of quartz. Accordingly, the composition of the two clay bases was:

	Kaolin.	Kaolin quartz mixture.
Silica.....	46.4	70.0
Alumina.....	39.7	22.2
Chem. water.....	13.8	7.7
	99.9	99.9

Starting with each clay base and using a pure grade of commercial calcium carbonate, four mixtures corresponding in composition to the following four formulæ were prepared by grinding wet in a porcelain lined ball-mill:



These eight cements formed one-half of the series, while the other half consisted of mixtures based on the same two clays, but built up with a dolomitic material in place of the calcium carbonate. This dolomite was

* W. M. Kennedy, *Transactions Am. Cer. Society*, Vol. IV.

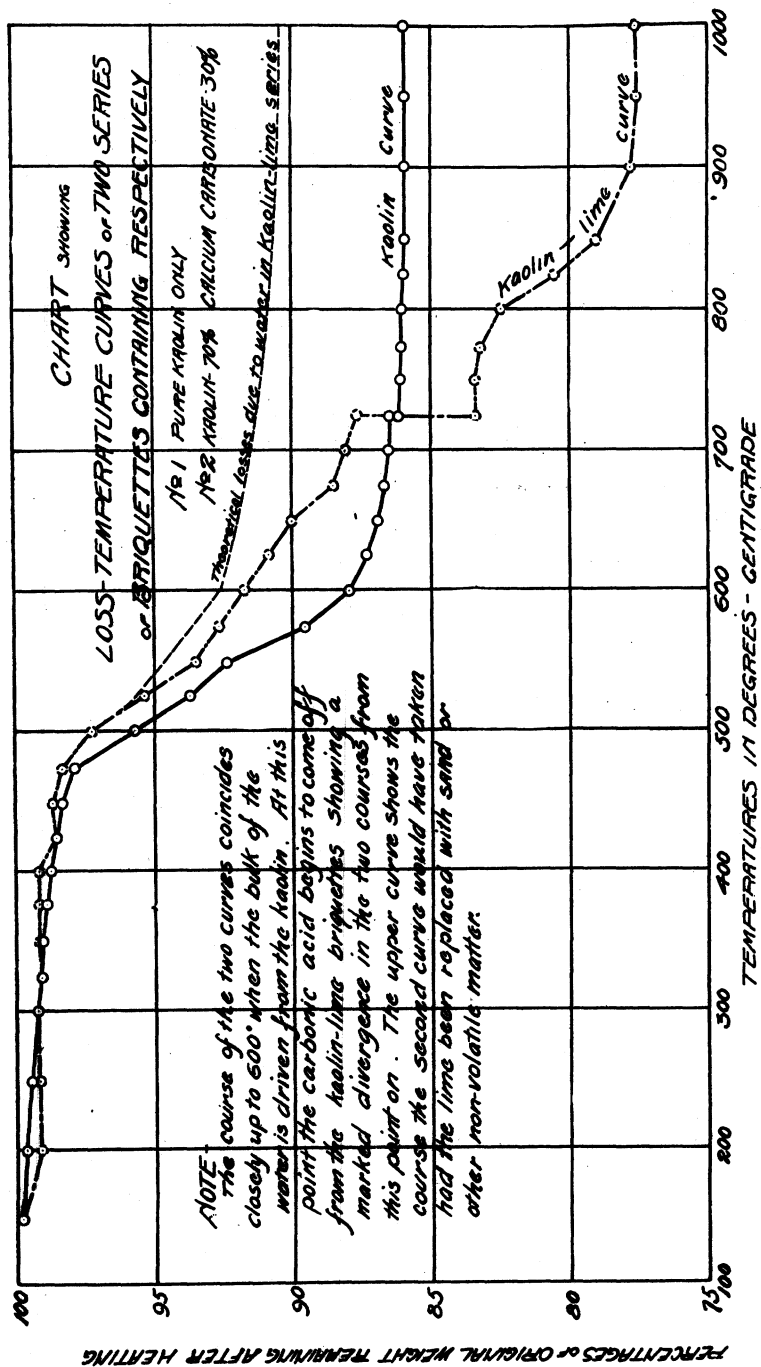
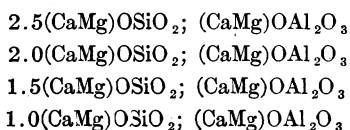


Fig. 18. Curve showing relative rates of loss on heating of calcareous and non-calcareous clays.

a soft marl from near Peebles, Ohio, and was used in three varieties differing slightly in composition. The composition was quite closely:

	Per Cents.
Silica.....	0.42
Alumina.....	0.54
Calcium carbonate.....	55.90
Magnesium carbonate.....	43.94

The eight dolomitic mixtures were likewise made to correspond to the four formulas:



These, of course, were prepared as in the lime series.

In the table on page 181 the approximate composition of these cements is shown.

Batch No.	Formula.	Clay Base.	Composition of Ignited Cement.				
			Silica, Per Cent.	Alumina, Per Cent.	Lime Cent.	Magnesia, Per Cent.	Number in Series.
1-4	2.5CaOSiO ₂ CaOAl ₂ O ₃	Kaolin.....	21.14	18.65	59.45	0.2	1
5-7	" ".....	Kaolin-quartz mixture.	27.41	8.77	62.88	.....	5
8-11	2.0CaOSiO ₂ CaOAl ₂ O ₃	Kaolin.....	23.49	20.68	55.39	0.2	2
12-15	" ".....	Kaolin-quartz mixture..	30.48	9.84	58.89	.....	6
16-19	1.5CaOSiO ₂ CaOAl ₂ O ₃	Kaolin.....	26.18	22.91	50.45	0.2	3
20-23	" ".....	Kaolin-quartz mixture..	35.73	11.40	52.31	.....	7
24-27	1.0CaOSiO ₂ CaOAl ₂ O ₃	Kaolin.....	29.85	25.58	44.54	0.1	4
28-30	" ".....	Kaolin-quartz mixture..	42.53	13.56	43.64	.....	8
31-34	2.5(CaMg)OSiO ₂ (CaMg)OAl ₂ O ₃	Kaolin.....	23.38	20.18	33.80	22.59	9
35-38	" ".....	Kaolin-quartz mixture..	28.60	9.57	37.09	24.79	13
39-42	2.0(CaMg)OSiO ₂ (CaMg)OAl ₂ O ₃	Kaolin.....	25.74	22.28	31.18	20.84	10
43-46	" ".....	Kaolin-quartz mixture..	32.34	10.72	34.13	22.81	14
47-50	1.5(CaMg)OSiO ₂ (CaMg)OAl ₂ O ₃	Kaolin.....	28.92	24.80	27.74	18.54	11
51-54	" ".....	Kaolin-quartz mixture	37.30	12.14	30.24	20.21	15
55-58	1.0(CaMg)OSiO ₂ (CaMg)OAl ₂ O ₃	Kaolin.....	32.41	27.94	23.70	15.84	12
59-62	" ".....	Kaolin-quartz mixture..	43.63	14.10	25.30	16.91	16

After being made up, ground and dried, these cements were burnt in large Hessian crucibles in a vertical test kiln of the Ceramic Department at the Ohio State University, the temperatures being determined by means of the Chatelier pyrometer. Contrary to expectations, the tendency to dust at higher temperatures was not marked with most of the cements. At 1250° C., all the cements with kaolin were vitrified or partially fused.

In regard to dusting (batch) numbers 1, 2 and 6 showed this tendency in the most striking manner. The dolomitic cements did not dust at all. In removing the content of the crucible, care was taken to reject all of the material clinging or fused to the sides. The crucibles were removed from the kiln as soon as the desired temperature was reached, being thus cooled very rapidly.

The cements were now ground and made up into briquettes, one cement, one sand, placed under a moist cloth, and when sufficiently hardened were placed in water for 28 days.

The results of the tests are given by the following table:

PURE LIME SERIES.

Number.	Clay base.	Formula of Cement.	Temperature of burning. °C.	Tensile strength, 1 cement; 1 sand 28 days in water. Pounds per sq. in.	Remarks.
1	Kaolin.	$(2.5\text{CaO})\text{SiO}_2 \text{ CaOAl}_2\text{O}_3$	900	....	Briquettes broke.
2	"	"	1,000	156	Hot and sticky.
3	"	"	1,100	....	Not tested.
4	"	"	1,300	39	Quick setting, dry and crumbly.
5	Kaolin-flint mixture	$(2.5\text{CaO})\text{SiO}_2 \text{ CaOAl}_2\text{O}_3$	900	181	
6	"	"	1,000	225	
7	"	"	1,100	145	Hot and sticky.
8	Kaolin.	$(2.0\text{CaO})\text{SiO}_2 \text{ CaOAl}_2\text{O}_3$	900	20	Softened.
9	"	"	1,000	183	
10	"	"	1,100	....	Not tested.
11	"	"	1,270	55	Dry and crumbly.
12	Kaolin-flint mixture	$(2.0\text{CaO})\text{SiO}_2 \text{ CaOAl}_2\text{O}_3$	900	182	
13	"	"	1,000	218	
14	"	"	1,100	111	Set too rapidly.
15	"	"	1,230	....	Broke up in 2 days.

PURE LIME SERIES—Continued.

Number.	Clay base.	Formula of cement.	Temperature of burning. C°.	Tensile strength. 1 cement; 1 sand 28 days in water. Pounds per sq. in.	Remarks.
16	Kaolin	$(1.5\text{CaO})\text{SiO}_2 \text{ CaOAl}_2\text{O}_3$	900	37	
17	"	"	1,000	108	
18	"	"	1,100	46	Softened.
19	"	"	1,230	....	Broke up.
20	Kaolin-flint mixture	$(1.5\text{CaO})\text{SiO}_2 \text{ CaOAl}_2\text{O}_3$	900	216	
21	"	"	1,000	211	
22	"	"	1,100	208	
23	"	"	1,230	....	Broke up.
24	Kaolin	$(\text{CaO})\text{SiO}_2 \text{ CaOAl}_2\text{O}_3$	900	....	Broke in clip.
25	"	"	1,000	96	
26	"	"	1,100	71	
27	"	"	1,230	....	Broke in 2 days.
28	Kaolin-flint mixture	$(\text{CaO})\text{SiO}_2 \text{ CaOAl}_2\text{O}_3$	900	188	
29	"	"	1,000	166	
30	"	"	1,100	46	
31	Kaolin	$2.5(\text{CaMgO})\text{SiO}_2 (\text{CaMgO})\text{Al}_2\text{O}_3$	850	261	
32	"	"	950	320	
33	"	"	1,050	148	
34	"	"	1,230	....	Broke up in 3 days.
35	Kaolin-flint mixture	$2.5(\text{CaMgO})\text{SiO}_2 (\text{CaMgO})\text{Al}_2\text{O}_3$	850	175	
36	"	"	950	235	
37	"	"	1,050	284	
38	"	"	1,230	....	Broke up.
39	Kaolin	$2.0(\text{CaMgO})\text{SiO}_2 (\text{CaMgO})\text{Al}_2\text{O}_3$	850	82	
40	"	"	950	80	
41	"	"	1,050	....	Softened.
42	"	"	1,230	....	Broke up in 2 days.
43	Kaolin-flint mixture	$2.0(\text{CaMgO})\text{SiO}_2 (\text{CaMgO})\text{Al}_2\text{O}_3$	850	251	Works up well.
44	"	"	950	256	
45	"	"	1,050	48	

PURE LIME SERIES—Concluded.

Number.	Clay base.	Formula of cement.	Temperature of burning, °C.	Tensile strength, 1 cement; 1 sand, 28 days in water. Pounds per sq. in.	Remarks.
46	"	"	1,250	....	Broke up in 2 days.
47	Kaolin	$1.5(\text{CaMgO})\text{SiO}_2 (\text{CaMgO})\text{Al}_2\text{O}_3$	850	....	Broke in clip.
48	"	"	950	....	"
49	"	"	1,050	....	"
50	"	"	1,250	....	"
51	Kaolin-flint mixture	$1.5(\text{CaMgO})\text{SiO}_2 (\text{CaMgO})\text{Al}_2\text{O}_3$	850	89	Briquettes broke
52	"	"	950	324	
53	"	"	1,050	....	
54	"	"	1,250	....	
55	Kaolin	$(\text{CaMgO})\text{SiO}_2 (\text{CaMgO})\text{Al}_2\text{O}_3$	850	....	Briquettes broke.
56	"	"	950	....	"
57	"	"	1,050	....	"
58	"	"	1,250	....	Slaked.
59	Kaolin-flint mixture	$(\text{CaMgO})\text{SiO}_2 (\text{CaMgO})\text{Al}_2\text{O}_3$	850	337	Briquettes broke in handling.
60	"	"	950	313	
61	"	"	1,050	....	
62	"	"	1,250	....	

The following conclusions may be deduced from a study of the above results:

1. The best temperature for burning calcareous Roman cements is 1000°C . Below this temperature hydraulicity is not fully developed, above it a non-hydraulic compound is evidently produced; whether on going still higher hydraulicity is restored has not been determined, but seems doubtful.

2. Roman cements having as a clay base pure kaolin are greatly inferior to cements containing a silicious clay base in each and every case. Whether this inferiority is due to the lack of silica or to the excess of alumina cannot be stated. But this seems to indicate that the hydraulicity of these cements is pozzuolanic in character.

3. The pozzuolanic character is emphasized by the fact that a decrease of as much as 10 per cent. of calcium oxide does not produce

any considerable decrease in tensile strength, indicating that as long as there is sufficient lime to change the quartz to "soluble" silica about the same hydraulicity is maintained. It cannot be said, therefore, that good Roman cements must correspond to a definite formula, as has been claimed by Jex, who lays down as the type formula a compound corresponding to $8\text{CaO}_3\text{SiO}_2\text{Al}_2\text{O}_3$; which, according to him, hydrates to $3\text{CaSiO}_3 \cdot 5\text{Ca}(\text{OH})_2 \cdot 2(\text{Al}_2(\text{OH})_3)$, thus resulting in 42.4 per cent. of meta-calcium silicate and 57.6 per cent. of calcium and aluminum hydrates.

4. The proper burning temperature of dolomitic Roman cements is about 950°C . and should be lower rather than higher.

5. Silicious dolomitic cements give rise to greater hydraulicity in every case than those containing pure clay substance as a base.

6. Dolomitic cements show a greater hydraulicity than calcareous cements. Whether or not this is due to a reinforcement of the pozzuolane reaction by a Sorel cement reaction cannot be said. It is possible that if the $2.5(\text{CaMg})\text{OSiO}_2$ cements with the 56 kaolin 44 quartz clay base had been burnt more rapidly up to 1300° it would have shown a reconstruction of hydraulicity, owing to the formation of a vitrified magnesian Portland cement. None of the less basic cements, however, could have shown such a behavior. If it had been still more basic, corresponding, about, to $2.8(\text{CaMg})\text{OSiO}_2 \cdot 2(\text{CaMg})\text{OAl}_2\text{O}_3$ we could predict the formation of a Portland cement and hence a great rise in hydraulic strength with certainty.

Similarly, a Roman cement high in lime, approaching a tri-calcium silicate, would become by vitrification a Portland cement with great increase in strength. This is actually realized in the high calcium natural cements of the Lehigh Valley in Pennsylvania. If the tensile strength of such basic cements, calcareous or magnesian, were plotted co-ordinate with the temperature of burning, we would have a curve showing two minima and two maxima. The first minimum would of course be due to under burning, the first maximum would be reached by the proper maturing temperatures, 1000° and 950° , respectively; the second minimum would be due to too high a temperature while the body still remains in the earthy condition, but becomes dense, and the second maximum is the result of vitrification, that is, the production of more complex hydraulic compounds.

Gilmore's Work.—This fact was already realized by General Gilmore in his treatise on "Limes, Hydraulic Cements and Mortars," 1870, where he gives, on page 158, curves bringing out this fact. He took Ulster county, N. Y., cement, burnt it at four stages represented by 1, 2, 3, 4, respectively, where 1 stands for underburnt rock, 2 for properly

burnt cement, 3 for over-burning without vitrification, 4 for vitrification. The composition of the stone (layer No. 12) was as follows:

	Per Cents.
Silicious residue.....	19.64
Alumina.....	7.52
Ferric oxide.....	2.38
Calcium carbonate.....	30.72
Magnesium carbonate.....	35.10
	95.36

The ordinates represent the breaking weights of rectangular parallel-pipedes, 2 inches by 2 inches by 8 inches, the pressure being applied at

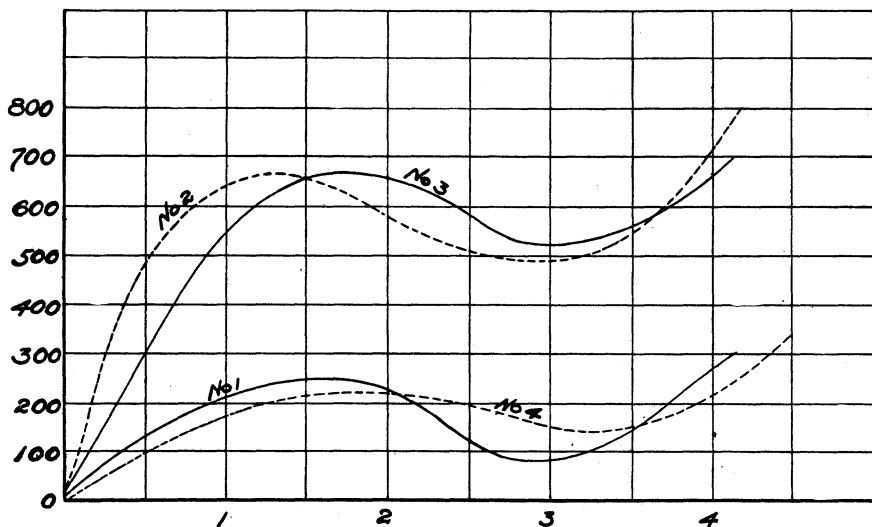


Fig. 19. Gilmore's curves, showing double maxima and minima in strengths of cements by variation in burning temperature.

the middle. Curve No. 1 represents 1 volume cement to 2 volumes sand, age 95 days; No. 2, neat cement, 95 days; No. 3, neat cement, 60 days; No. 4, 1 volume cement to 1 volume sand, 60 days.

The same results are recorded by Feichtinger as having been obtained by Gaetschenberger with dolomitic marl from near Heidelberg.

Summary of the Results.—Summarizing the results in regard to the burning of Roman cements, we can make the following statements:

1st. For Roman cements, high in lime, approaching the tri-calcium silicate and low in magnesia, best burning temperature is 1000° C. Such stone can be made into Portland cement by vitrification. This cannot be

done successfully, however, with a Roman cement equipment, but requires more elaborate and expensive machinery and kilns.

2nd. Roman cements, lower in lime than 1, and free from magnesia, can only be burnt at 1000°C .

3rd. Roman cements, high in magnesia, should only be burnt at 950°C , as the great strength produced by making a magnesia Portland cement is counterbalanced by the danger of inconstancy in volume due to the two rates of hydration of lime and magnesia, the latter hydrating only after the first has assumed a stony hardness, thus breaking the structure of the cement. In very sandy mortars and some kinds of work they might perhaps be used, but at this stage of our knowledge concerning cements they cannot be considered a safe proposition.

4th. Cements, dolomitic, less basic than the subsilicate, to be burnt only at or about 950° .

These facts are well realized by natural cement manufacturers, who endeavor to burn their cements below the point at which decrease in strength occurs, and this they accomplish by leaving some of the calcium carbonate in dolomitic rocks undecomposed. It is hence unreasonable to demand of Roman cement manufacturers that they produce cement burnt to a point at which all volatile matter is expelled, but, of course, this does not mean that raw rock should be allowed to be ground together with the cement.

Artificial Roman Cement.—The question has been raised as to the feasibility of producing an artificial Roman cement by blending clay and limestone in the proper proportion, burning the mixture to a low temperature, and grinding the resulting soft material to the usual fineness. There is no doubt as to the technical feasibility of this plan, and the large dolomitic limestone deposits of Ohio could thus be utilized without difficulty, but the commercial aspect is not promising, especially since the cost of production of Portland cement is being lowered so decidedly. This plan, however, might be carried out in countries without proper Portland or natural cement materials, but possessing dolomitic limestones.

The Kilns.—The kilns used differ somewhat in size and shape in different localities. In the Louisville district they are cylindrical in shape, consisting of a cylindrical iron shell lined with fire-brick, about 45 feet high, and 16 feet in diameter; in the Rosendale district many kilns are 10 feet in diameter (inside), and about 29 feet high; near Akron, N. Y., the writer saw a kiln oblong in section, 15 feet by 8 feet and 25 feet high. At Milwaukee a kiln is used, 11 feet in diameter (inside), and 36 feet high. In the Rosendale district the kilns usually are built together in a row of masonry braced by heavy timbers and iron rods. All the kilns are narrowed at the bottom to a neck, through which the calcined cement is discharged. The coal, usually anthracite, or a good grade of

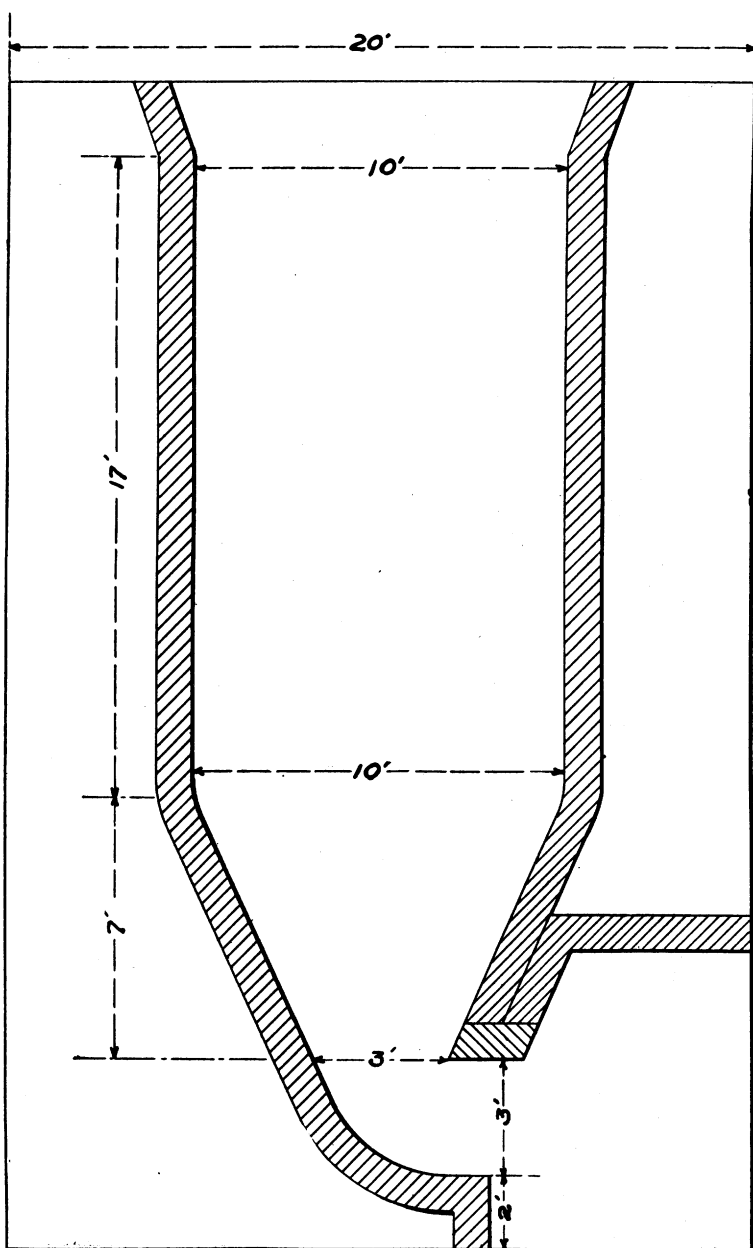


Fig. 20. Cross-section of the type of natural cement kiln in most general use.

bituminous, is charged, together with the stone, in alternate layers. For 100 pounds of stone, about 10 pounds of good anthracite coal is charged; in the plant at New Lisbon, Ohio, it is customary to add sixteen shovels of good bituminous coal to a carload of about 3,500 pounds of stone.

The kilns employed in the natural cement industries have undergone practically no change during the last thirty or forty years, being simply vertical shafts with contracted bottom, of various, but not greatly differing dimensions. All of these kilns are now operated on the continuous plan, since not only the output, but also the quality, of the cement is superior to that burnt in the periodic shaft kiln. The quality of the cement could be further improved by the use of furnaces arranged around the circumference of the kiln, so that the fuel would not need be in contact with the stone and also the distribution of the heat could be effected with much greater efficiency. However, the greater expense of operating the kilns would probably prohibit its use. Such kilns have been tried by American cement makers, and as far as qualitative results are concerned were eminently successful. Some improvements have been made in regard to the distribution of air in the ordinary kiln among which Campbell's grate in the kiln bottom might be mentioned. There is no doubt but that natural cement could be burnt in the rotary kiln with good success, especially since the time of burning would thus be considerably shortened, resulting in a better quality of cement. The fuel consumption would, of course, be greater, but the greater uniformity and quality of the product would compensate to some extent for the waste in fuel. A rotary kiln, of the usual size, 60 feet by 6 feet, should have no difficulty in burning on an average 250 barrels of natural cement per day, as no delay due to "rings" would occur and the lining would not be attacked as vigorously as it is in Portland cement kilns. Obviously the cement rock would have to be reduced to about pea size, at least, before being fed into the kiln.

Rough Grinding.—As usually practiced, the selected burnt rock is sent first to the "cracker" and from there to the millstones. The cracker consists of a frustrum of a cone, made of cast-iron with a chilled shell which revolves within the inverted frustrum of a right hollow cone. Both are provided with corrugations for breaking up the stone. The lower parts of the cones make a smaller angle with the vertical axis than the upper, thus securing a more gradual reduction of the stone. The diameter of the shell is about 15 inches at the top and 6 inches at the bottom. The height is about 18 inches. A cracker of this size will grind enough stone for about 300 barrels per day, making 80 to 85 revolutions. From the cracker the crushed material passes on to the mills. In some plants the crushed stone is screened on the way to the mill, while in others everything goes through the fine grinding machine. An ingenious system of screening has been perfected by Berthellet in which all of the

crushed material makes a complete circuit, the fine material being constantly removed and the coarser particles being even carried along with the fine grindings from the buhr mill, since they insure better working of the screens.

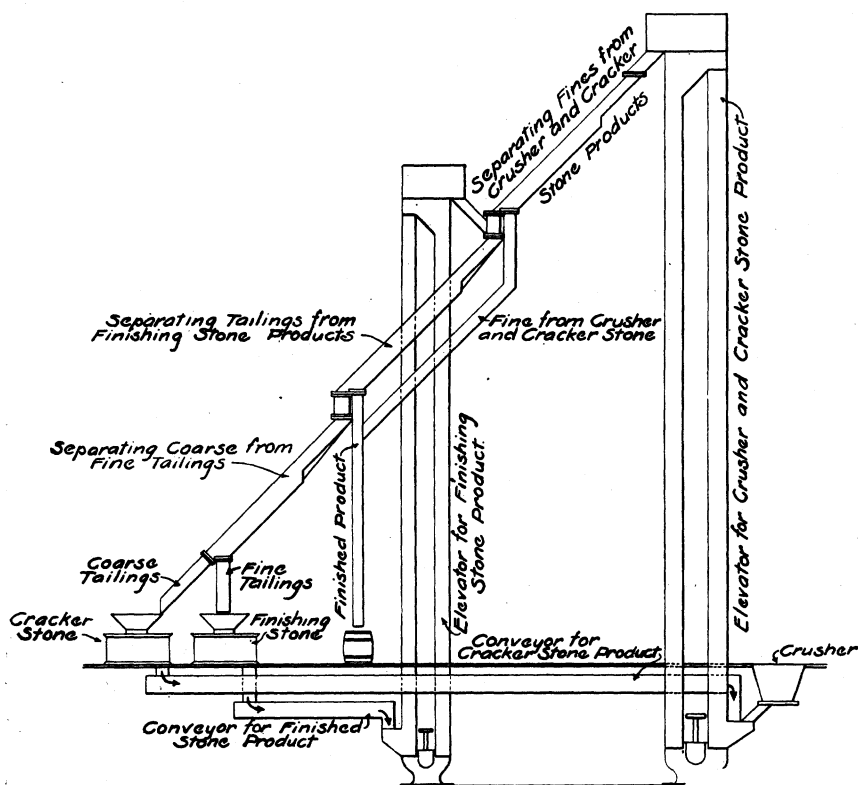


Fig. 21. Berthellet system of screening.

Fine Grinding.—The mill most frequently used is the old-fashioned buhr mill, from 3 to 5 feet in diameter. One of the large size mills will grind about 10 barrels of cement per hour. These mills require, however, frequent dressing, which is equivalent to considerable expenditure of time and money. Emery mills are now being used in considerable numbers, which have proven more efficient, as they need less dressing. A 42 inch emery mill will grind from 18 to 20 barrels of rock per hour, 95 per cent. passing the 100 mesh sieve. The power required is about 15 to 18 horsepower. The grindings from the finishing mill are usually screened and delivered to the hopper, from which chutes take the cement to the packing room. Usually the rock cement is not stored, but shipped at once. This, of course, is a matter depending on the composition of the rock. Very basic cements must be stored.

Some cement makers have adopted the tube mill for fine grinding. Though requiring more power, the tube mill can easily grind 250 barrels and has the advantage of doing away with the screening. It seems that its general adoption would be a progressive step in spite of the greater amount of power required, especially since it eliminates the troublesome attention required in the dressing of stones. The tube mill must invariably be preceded by an intermediate grinding machine, a disintegrator or Kent mill.

Variability of Product.—In the nature of the case the rock cement makers labor under the great disadvantage of being compelled to work with natural materials whose composition cannot be controlled or regulated. If the rock happens to be of the right composition, all is well; if not, nothing can be done. It is idle to claim that these natural variations in composition can be neglected; for poor cement is liable to result, and will reach the market unless its character is discovered by testing. But the limits allowable are quite wide, owing to the pozzuolanic character, and some cements have never given any trouble.

Improvement in Quality by Treatment.—Since our American cement rocks are principally of the mono-silicate type (O.R.1:1) and frequently fall below this degree of basicity, and again since the prevailing reaction seems to be pozzuolanic in character, the idea is at once suggested that an addition of dry, hydrated lime might improve many of these cements, just as the hydraulicity of granulated furnace slag is increased by the addition of slaked lime. Following this line of reasoning, the writer made some experiments carried out by burning typical cement rocks obtained from the Rosendale, Louisville and Utica districts and grinding the calcined rock together with dry slaked lime in a ball-mill.

The following results were obtained, the comparisons being made with the identical three samples of cement rock:

Number.	Kind of cement.	Tensile strength in pounds per sq. in. 1: 1, 28 days.	Remarks.
1	Ground rock alone.....	...	Checked and swollen.
2	No. 1 plus 5% lime.....	230	(Burnt too long.)
3	Ground rock.....	135	
4	No. 3 plus 5% lime.....	200	
5	Ground rock.....	100	
6	No. 5 plus 5% lime.....	270	

The rock in each case had been overburned somewhat. But the increase in strength, due to the small amount of dry slaked lime, is very

remarkable, and it might be well for manufacturers to take up this matter, as it might open a way for greatly improving their product. The cost of adding dry slaked lime to the cement is insignificant compared with the results obtained, especially as, in addition, it causes the cement to work much smoother under the trowel. It might be suggested to add the lime when using the cement. Though even this increases the resulting strength, the results are much more striking when the lime is ground together with the cement. Messrs. H. B. Nichols and Ross E. Hamilton, students in the Department of Civil Engineering, Ohio State University, tested Louisville cement by making it up with varying amounts of fat slaked lime and sand in the proportion 1:2, as shown by the accompanying table:

Louisville cement.	Fat lime. per cent.	Tensile strength 1: 2 after 26 weeks. Pounds per sq. in.
100	..	292
96	4	335
92	8	325
90	10	325
85	15	322
80	20	357
75	25	304
70	30	335
50	50	170

These experimenters, when making up several Portland cements with fat lime, found not only no increase, but at once a decrease in tensile strength with 1:3 mixtures, just as was to be expected, owing to the fact that Portland cement already has its quota of lime.

Strength of Roman Cements.—In regard to the strength of Roman cements it should be said that in most cases they possess ample crushing strength for all practical purposes, but have two great drawbacks, viz: first, lack of uniformity; second, inconstancy in volume. The greatest difficulty in using Roman cements is their liability to increase in volume, which makes them unsuited for exact work like sidewalks and similar uses. For foundations, especially when used in very sandy mortars, the natural cements answer many purposes very well. At present, with the constantly lowering price of Portland cement, the natural cement industry has a difficult position, which can be improved only by bringing the quality of the rock cements up to the highest possible point.

This means the rejection of unsuited rock based on chemical examination, uniform burning, and fine grinding, together with any other improvements like the addition of dry slaked lime, whenever found beneficial. A great deal of the prejudice against natural cements is based on erroneous conceptions and they are barred frequently from fields in which by virtue of their cheapness they might be used with economy.

In regard to the strength of Roman cements, the following figures might be cited. Tetmayer found the average specific gravity of Swiss Roman cements to be 2.98, and their average strengths as given in table below. These cements are principally calcareous.

Tensile and Crushing Strength of Swiss Roman Cements, According to Tetmayer.

Mixture.	Time in water.	Tensile strength in pounds sq. in.	Crushing strength in pounds sq. in.
Neat	28 days	203	2,347
"	84 "	356	3,871
"	210 "	401	5,600
"	365 "	416	6,676
1: 3	28 days	190	1,717
"	84 "	312	2,884
"	210 "	396	4,025
"	365 "	407	4,517

Standard Test.—With reference to American natural cements, the following minimum and maximum tensile strengths per square inch have been suggested by a committee of the American Society of Civil Engineers:

Neat Cement—One day; one hour, or until set, in air, the rest of the 24 hours in water, from 40 to 80 pounds.

One week; one day in air, six days in water, from 60 pounds to 100 pounds.

One month (28 days); one day in air, 27 days in water, from 100 to 150 pounds.

One year; one day in air, the remainder in water, from 300 to 400 pounds.

Sand Mixtures—1 cement: 1 sand, by weight.

One week ; one day in air, six days in water, 30 to 50 pounds.

One month (28 days) ; one day in air, 27 days in water, 50 to 80 pounds.

One year ; one day in air, the remainder in water, 200 to 300 pounds.

The specific gravity of Roman cements varies so greatly that it cannot be considered a criterion of its value.

NATURAL CEMENTS IN OHIO.

This industry is very insignificant in this State, being represented at present only by one plant in operation, two others being idle. The plant in operation is located at New Lisbon, while the other mills are at Defiance and Bellaire. The mill at New Lisbon is a small plant, having five kilns, of which, however, only two or three are operated at present, having a capacity of from 100 to 150 barrels a day. The mechanical outfit is very simple, consisting of a cracker and buhr mills, one 3 foot buhr mill turning out about 100 barrels a day. A 50 horsepower engine operates the mill. The stone is mined, eight miners and one driver being employed. For each car of 3,500 pounds, 16 shovels of good bituminous coal is added when charging the stone into the kiln. The kilns are about 30 feet high and have an inside diameter of about 10 feet. Three of the kilns are built together in a block, while two of them are iron jacketed and separated. Once a day, in the morning, each kiln in operation is drawn, furnishing about 50 barrels. When operating two kilns, 14 men are employed altogether, eight miners and one driver, two kiln men and three mill men. When running two more kilns, three more men are needed.

The mill at Defiance works the dolomitic rock, whose outcrop forms the bed of the Auglaize River, and is a material high in bituminous matter and pyrites. The latter are especially obnoxious, and form regular bands, which are rejected as much as possible. On burning, the iron sulphide causes the cement to clinker and stick, forming a sponge-like porous mass which is thrown away. The two kilns are cylindrical, 18 feet high, and 6 feet inside diameter, widening out at the bottom so as to minimize sticking as much as possible. Each kiln is fired from two furnaces, a cheap grade of wood having been the fuel used. From each furnace two openings lead into the kiln space. Owing to the fact that the stone is high in bituminous matter, the fuel necessary is small in amount, from one-quarter to one-half cord of wood per day. The chief difficulty is in holding back the burning so as to prevent clinkering and to oxidize the iron pyrites. Sometimes the clinkered cement chokes up the holes leading from the furnaces into the kiln. The stone is drawn at short intervals, every thirty minutes, from five to eight, or even twelve wheelbarrows being obtained. At the same time a corresponding amount of stone is charged on top. The machinery consists of a crusher and a buhr mill, three feet in diameter, which must be dressed every three days. The or-

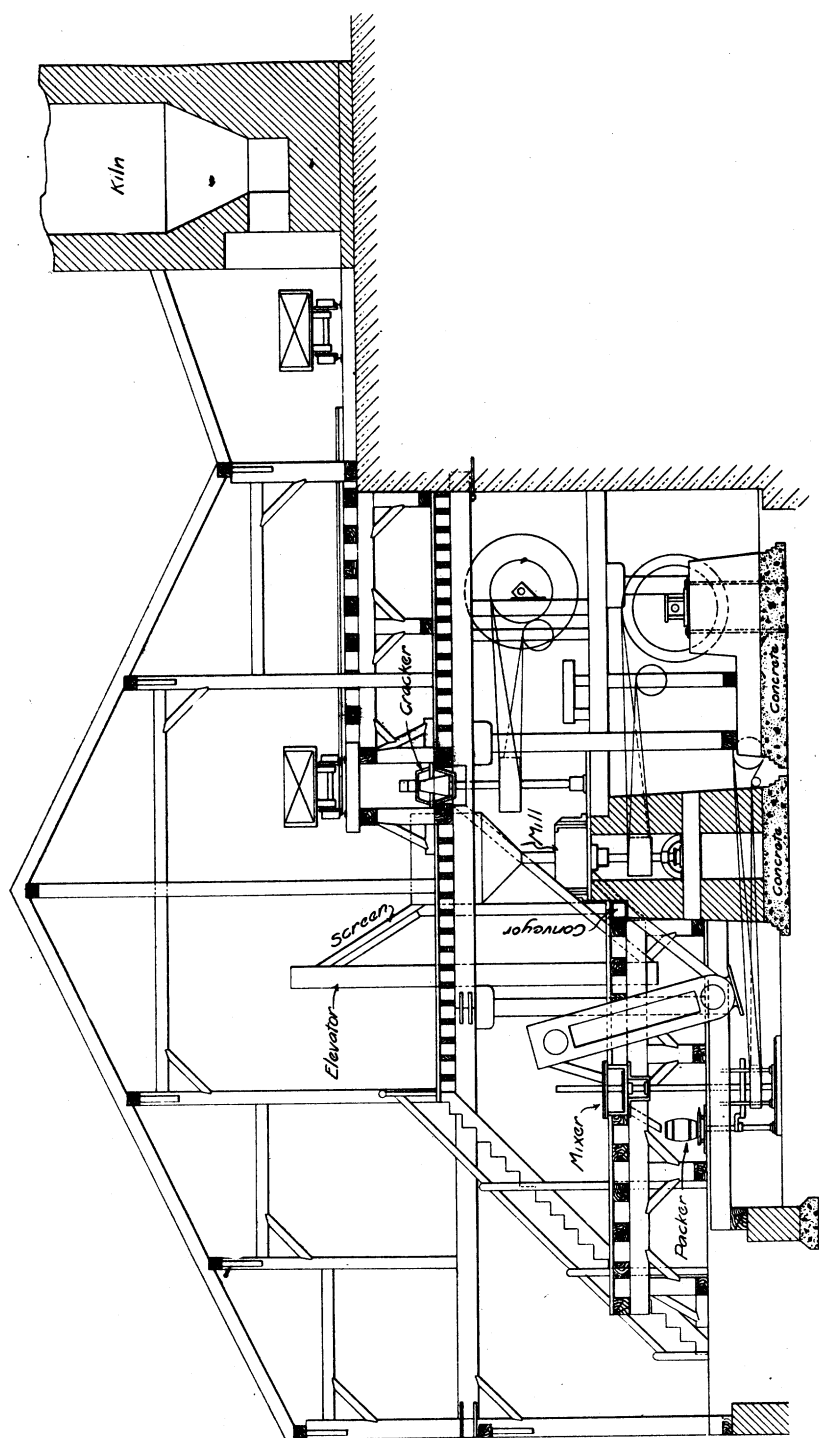


Fig. 22. Cross-section of a natural cement plant.

dinary capacity of the kilns would be 500 barrels, but owing to the troublesome material, it is only about 200 barrels. Sometimes large blocks of clinker must be chiseled out from the kiln, and of course rejected.

Aside from this difficulty, the quality of the cement is good, it having been used successfully in a great many building operations. A peculiar and interesting fact observed is the tendency of the burnt pieces of the stone to split up into small cubes on weathering, affording a striking example of the influence of the crystallization of the pyrites upon the bed structure of the whole deposit.

The maximum thickness of the hydraulic rock is said to be 27 feet the greatest thickness at which it is mined is eight feet, but as a rule about four to five feet are quarried. There are two layers of the stone, which shows a most decided shale structure, and is easily mined. One is a black, the other a gray shale; the first contains the greater amount of bitumen. At this mill, 200 barrels of cement can be produced per day with 11 men, distributed as follows:

- 1 engineer,
- 4 kiln men,
- 1 general help,
- 2 mill men,
- 2 quarry men,
- 1 driver with team.

By using a rotary kiln in which a distinct roasting stage is maintained it is quite probable that this stone could be burnt much more satisfactorily. It is the intention of the proprietor, Mr. Frank Wilhelm, to resume operations on a larger scale.

CHAPTER V.

ON THE NATURE OF PORTLAND CEMENT.

Portland cement is an artificial silicate produced by intimately blending clayey and calcareous materials, burning them to vitrification, and grinding the resultant slag-like mass to a fine powder. This powder, if of the proper composition, will hydrate and harden in water to a stone-like mass, of practically constant volume, which shows considerable tensile and crushing strength and is able to cement together relatively large quantities of sand. In composition it varies between the following limits:

Ingredients.	Per cents.	
	Minimum.	Maximum.
Silica.....	19	26
Alumina.....	4	11
Ferrie oxide.....	2	5
Lime.....	58	67
Magnesia.....	0	5
Sulphuric acid.....	0	2.5
Alkalies.....	0	3.0

The table on page 195 shows the composition of ten American Portland cements of well established reputations:

The average American Portland cement calculates to the formula 1.10CaO , 0.363SiO_2 , $0.074\text{Al}_2\text{O}_3$, $0.021\text{Fe}_2\text{O}_3$ allowing for the presence of 0.83 per cent. of CaO as sulphate. Calculated to the basis of silica equal to unity, we have the general formula: 3.04CaO SiO_2 , $0.23\text{Al}_2\text{O}_3$, $0.058\text{Fe}_2\text{O}_3$. For purposes of comparison, especially with reference to the study of the clay base of cements, we might calculate still another formula, making the alumina equivalent equal to unity, obtaining: 14.99CaO , 4.93SiO_2 , Al_2O_3 , $0.284\text{Fe}_2\text{O}_3$. The reason for making alumina equal to

Chemical Composition of Standard American Portland Cements.

Percentages.								
Number.	Silica.	Alumina.	Ferrie Oxide.	Calcium Oxide.	Magne- sium Ox.	Alkalies.	Sulphuric Anhy- dride.	Ratio $\frac{\text{Si O}_2}{\text{Al}_2\text{O}_3}$
1	21.22	7.51	3.83	63.75	0.82	not det.	1.58	2.82
2	21.20	7.90	not det.	63.14	2.40	not det.	1.37	2.68
3	21.93	5.98	2.35	62.92	1.10	not det.	1.54	3.67
4	23.36	8.07	4.83	58.93	1.00	0.50	0.85	2.90
5	22.89	8.00	2.44	63.38	2.30	not det.	not det.	2.86
6	22.24	7.26	2.54	64.96	2.26	not det.	0.41	3.07
7	22.04	6.45	3.41	60.92	3.53	not det.	2.25	3.42
8	21.24	7.85	4.14	63.22	0.28	0.68	1.11	2.71
9	20.83	10.58		63.30	2.86	not det.	1.13	.....
10	21.10	8.61	3.21	61.62	2.84	not det.	1.69	2.45
Average	21.76	7.51	3.31	62.61	1.94	not det.	1.19	2.90

For comparison, four well-known German Cements are given:

11	19.35	7.00	4.50	63.75	.....	not det.	not det.	2.76
12	21.14	6.30	2.50	66.04	1.11	not det.	not det.	3.36
13	22.69	7.30	2.28	62.28	1.08	not det.	not det.	3.10
14	24.90	8.00	3.22	59.38	0.38	not det.	not det.	3.11

No. 11, Dyckerhoff; No. 12, Germania; No. 13, Porta; No. 14, Alsen.

unity is based on the fact that the fundamental formula of clay substance is $\text{Al}_2\text{O}_3, 2\text{SiO}_2, 2\text{H}_2\text{O}$, showing one molecule of alumina. This last formula therefore tells us that the average clay base corresponds to clay of the formula: $\text{Al}_2\text{O}_3, 0.284\text{Fe}_2\text{O}_3, 4.93\text{SiO}_2$, showing theoretically 2.93 molecules of free silica under the assumption that none of the alumina is part of feldspathic minerals, an assumption which does not hold for impure clays. The oxygen ratios between the lime, alumina and silica are: 3.04:0.69:2 making Portland cement equal to a sub-silicate of calcium. These molecular ratios are not exact owing to the presence of varying amounts of coal ash.

We might hence compare Portland cement with a basic slag with which it shows, indeed, many similarities. In nature, we do

not find the exact analogies of Portland cement. From what we know of Portland cement at present we can say that it is, mineralogically speaking, a basic rock and its closest approach in the natural group of rocks is the peridotite group whose principal minerals are olivine, pyroxenes, hornblende and garnet.

REVIEW OF THE INVESTIGATIONS ON THE CONSTITUTION OF PORTLAND CEMENT.

The question as to what Portland cement really is has received a great deal of attention from many investigators, but it seems so far that the closest approach to an accurate conception of the structure of Portland cement has been made by mineralogical examinations while chemical investigations have failed more or less completely. It is interesting to examine the various methods by which investigators have approached the subject and, hence, in the following paragraphs a brief review of some of the work done by various men will be given. Much has also been written by men who base their conclusions on theoretical reasoning entirely. Such contributions are not considered.

The work done in this direction may be classified under several headings indicating the chief method by which it has been endeavored to determine the structure of Portland cement.

1. Mineralogical (microscopic) examination.
2. Study of synthetic mixtures.
3. Study of hydration reactions.
4. Determination of calcium oxide.
5. Study of heat reactions.

Of course, no investigator has confined himself to any single method, but most of the experimenters have paid special attention to one line of attack.

MINERALOGICAL INVESTIGATIONS.

The Work of Chatelier.—The first investigator to approach the subject along these lines was Chatelier,* who attacked the problem in 1887.

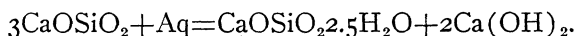
In this year he published his classical work on the constitution of Portland cement based on microscopic analysis, in which he states that he found the main constituents of Portland cement to consist of (1) colorless double-refracting, cubical crystals; (2) between these a darker substance, double-refracting, but without crystalline structure. In addition he found several accessory constituents.

- (a) Slightly yellowish crystals, opaque and showing striation.
- (b) Very small crystals with rather strong double-refraction.
- (c) Finally, zones of matter without influence on polarized light.

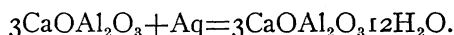
Constituent No. 1 was called, later, alite; No. 2, celite; a, belite; and b, felite. Chatelier considers the alite as 3CaOSiO_2 , this being the

**Recherches Experimentales Sur la Constitution Des Mortiers Hydrauliques, Annales Des Mines, 1887.*

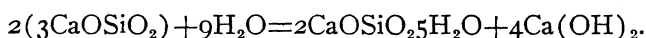
active element of cements, par excellence, which hydrates according to the following reaction:



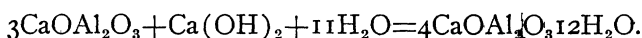
In addition to this compound, the Portland cement contains a tri-calcic aluminate, which is relatively unstable, but sets rapidly in water, and if present in too large amounts may cause the destruction of the cement. It hydrates according to the reaction:



Chatelier thus considers Portland cement as composed of tri-calcium silicate, with a certain amount of calcium aluminate and ferrate, besides mono and dicalcium silicates. The hydration of the cement he expresses by the two reactions:



Then a reaction takes place between the calcium hydrate, water and calcium aluminate forming a basic calcium aluminate:



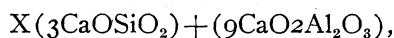
The hydrated basic aluminate determines the setting of the cement, while the hardening is fixed by the tri-calcium silicate. Chatelier fixes the amount of lime necessary for Portland cement by the expression:

$$\frac{\text{CaO}}{\text{SiO}_2 - \text{Al}_2\text{O}_3 - \text{Fe}_2\text{O}_3} > 3$$

in which CaO, SiO₂, Al₂O₃, Fe₂O₃ represent the number of equivalents of these substances present. The other limit he fixes by the expression:

$$\frac{\text{CaO}}{\text{SiO}_2 + \text{Al}_2\text{O}_3 - \text{Fe}_2\text{O}_3} < 3$$

The Work of Toernebohm.—Toernebohm practically checked the petrographic work of Chatelier, but arrived at a different composition of the compounds. According to him the Portland cement formula is:



in which the value of X fluctuates around 9. This investigator separated the minerals found by means of the Thoulet solution.

The Work of Liamin.—The next worker along petrographic lines was Liamin,* who produced a series of micro photographs of hardened

*Report of the Imperial Russian Technical Society, 1897.

cements showing the interlacing crystals of lime hydrate and lime-alumina silicates forming the hardened cement. Beside these, crystals were found strongly resembling nephrite. But the main active constituent, according to Liamin, is the lime hydrate which forms crystals frequently 1 mm. long. In hardening, the crystals of calcium hydrate and the nephrite-like crystals increase in magnitude. The anhydrous cement contains practically all of the lime combined, the principal mineral present being probably the sub-silicate of lime, which in hydration breaks up into a simpler silicate and calcium hydrate. The two methods of quantitative separation of the different constituents adopted by Liamin were:

1. Mechanical separation of the ground, hardened, cement by means of solutions of varying specific gravities.

2. Determination of the water of hydration at different temperatures. Liamin made the assumption that the water of hydration of the hydro-silicates leaves at 160° C., while the calcium hydrate loses its water between 450° and 480° C., an assumption by no means proven.

The liquids employed by this investigator in making the mechanical separation of the different minerals of the cement were:

a. Yellow methyl iodide, specific gravity 3.34

b. Benzene, specific gravity 0.89

By means of a mixture of these liquids of 2.3 specific gravity the lime hydrate was washed out and washed free from other constituents by means of the benzene. No trouble was experienced in removing the calcium hydrate, owing to the close specific gravities of the hydrate, 2.18, and of the liquid, 2.3. The amount of calcium hydrates thus obtained he checked by means of the second method. By determining the amount of water expelled at 160° C., and the quantity set free at 480° the amount of free calcium oxide can be calculated, for 18 parts of water correspond to 56 parts of the oxide. If thus

a=total loss of weight on igniting the hardened cement,

b=the loss of hygroscopic water at 100°,

c=the loss of water of hydration at 160°,

d=content of carbon dioxide and,

e=water content of the calcium hydrate,

e=a-(b+c+d), and

$$e \times \frac{\text{molecular wt. calcium hydrate}}{\text{molecular wt. water}} = e \times \frac{74}{18} = 4.11 \times e = \text{total amount of}$$

calcium oxide in the Portland cement.

Liamin found in 5 Portland cements

after 7 days hardening from 13.2 to 22.9 per cent. $\text{Ca}(\text{OH})_2$.

after 28 days hardening from 26.3 to 32.3 " " "

after 60 days hardening from 30.9 to 33.1 " " "

after 180 days hardening from 31.6 to 33.6 " " "

after 365 days hardening 32.0 " " "

The two methods of separation appeared to check very well. However, his ingenious and elegant method is open to the objection that neither the water of hydration of the hydrosilicates nor the water of the calcium hydrate has a definite expulsion temperature. In fact, laborious experiments made by the writer for the Ohio Geological Survey have shown that it is impossible to distinguish with any degree of accuracy any particular stage in the dehydration curve. It also requires red heat to expel all of the water of hydration.

The Earlier Work of Richardson.—In 1902 Dr. Clifford Richardson, an American investigator, prepared the tri-calcium silicate synthetically by fusion in the oxy-hydrogen flame, as well as non-dusting dicalcium silicates, both hardening in moist air and water. By means of micro-photographs, he illustrated the crystalline character of Portland cement, and makes the statement that it is a solid solution. This claim has been made by numerous investigators for the last ten years or more, but none of them have, as yet, produced satisfactory physical-chemical data for the purpose of proving this hypothesis beyond all doubt, though at present it would not seem a difficult matter to study the melting points and cooling curves by means of the electric furnace and the optical pyrometer. There is every reason to believe that all slags and slag like materials are solutions, and the work of Howe, Akerman,¹ Vogt,² Hofman,³ Ashley,⁴ has furnished important contributory evidence, but we have as yet no right to say that Portland cement is a solid solution, just as the same thing has not been proven for slag and glasses. As has been said, a thorough survey of all the physical properties of pure Portland cements must be made with reference to the specific volume, heat of formation and other physical data made mention of elsewhere.

The Work of Passow.—Dr. Passow, in 1903, examined Portland cement clinker microscopically, and found essentially two predominating constituents, a white crystalline mass, alite, and a dark ground mass or magma. These two constituents are the hydraulic bodies of Portland cement. If, however, a third crystalline substance appears which is characterized by distinct striations, similar to those shown by plagioclase under the microscope, the hydraulicity is impaired in the proportion in which this matter, felite, appears. According to Passow, this offers a ready means of judging the quality of Portland cements, enabling one to detect cements too high in clayey matter; that is, cements approaching too closely the bisilicates.

¹ *Stahl und Eisen*, 1890, p. 424.

² *Betraege zur Kenntniss der Mineralbildung in Schmelzmassen*, Christiania, 1892.

³ *Transactions Amer. Inst. Min. Eng.* Vol. 29, p. 682.

⁴ *Ibid.*, Vol. 31, p. 854.

The white crystalline matter, as well as the dark ground mass, can readily be observed in the accompanying micro section made by the writer.

The large crystal seen is a fine specimen of the alite found in normal Portland cements.



Fig. 23. A large crystal of "Alite" in Portland cement clinker (highly magnified).

The Later Work of Richardson.—The most thorough microscopic study of Portland cement is represented by the recent work of Dr. Clifford Richardson,* in which this investigator made an exhaustive experimental series involving various combinations of the mineral constituents of cement. Thus he arrives at the result that pure clinker consists of two distinct solid solutions, alite and celite, the first being tri-calcic aluminate dissolved in tri-calcic silicate, the second di-calcic aluminate dissolved in di-calcic silicate. These, though miscible in the molten state, are not so in the solid form. The limits of the proportions of alite and celite depend on the basicity and the ratio of silicate to aluminate and are roughly 3 to 1 and 6 to 1. This contribution furnishes the most valuable evidence for the solid solution theory as yet produced, but confirmatory proof based on other physical chemical methods of attack, such as the study of cooling curves, is still necessary for the final acceptance of this view.

THE STUDY OF SYNTHETIC COMPOUNDS.

This line of work was begun early in the scientific history of Portland cement. It might well be said that Vicat, in France, was the pioneer in this kind of experimental work on a scientific basis, followed by Rivot, Chatoney and Fremy. In Germany we find Heldt, Fuchs, Schott,

*Address before the Association of Portland Cement Manufacturers, June 15th, 1904.

Michaelis, Feichtinger, Erdmenger, Dyckerhoff, Meyer, Hauenschild and others. Synthetic work of a high order was also done later by Chate-
lier, mentioned above in connection with his microscopic research. It
will be impossible to consider the work of all these investigators, but it
is the intention of the writer to cite a few in order to show the way
in which the problem has been attacked.

The Work of Schott.—The experiments of Schott,* though not of
recent times, deserves recognition inasmuch as he has brought out one or
two important facts. He made up a mixture of pure silica, alumina,
ferric oxide and calcium carbonate, whose composition after burning
was as follows:

Number of mixture	1	2	3	4
Silica.....	23.8	23.8	23.3	24.3
Alumina.....	11.4	.....	6.9	6.9
Ferric oxide.....	.....	11.4	4.7	4.8
Lime.....	64.8	64.8	65.4	64.1

On burning them to incipient white heat, finely grinding them and
making up with water, they all hardened exceedingly well, even No. 2,
containing no alumina. On adding 1.5 per cent. of caustic soda to No. 2
it became a brown mass of extraordinary hardness. To cements 3 and
4 still more lime was added, 7.7 and 8 per cent. respectively, whereupon
they broke down to a powder, which, however, when again made up
with water resumed the hardening process.

Up to about 1885 the various theories advanced defined in a more or
less definite way the chemical composition of the cement, but all that
practically resulted from these older investigations was the mention of
the fact that calcium oxide formed with silica and alumina basic silicates
and aluminates which on the addition of water harden by breaking
down to simpler compounds and free calcium hydrate. Some of these
experimenters also realized that the end products of the hydration reaction
are largely colloids.

Various Investigators.—Seftstroem produced fused masses of alu-
mina and lime corresponding to $3\text{CaOAl}_2\text{O}_3 : 3\text{CaO}_2\text{Al}_2\text{O}_3$ and CaOAl_2O_3 ,
by burning them in a forge. Winkler produced a rapidly hardening
mass, which, however, broke down to a powder, by heating 11 equiv-
alents of lime, 1 equivalent of potash and 4 equivalents of alumina to
incipient vitrification. On hardening the mass showed considerable heat-

* "Dingl. Polyt. Jour.," 202, 494 and 513.

ing. He also blended 8 equivalents of lime, 1 of potash and 4 of alumina, obtaining a more thoroughly vitrified mass, which, when powdered, hardened strongly in water, and heated but slightly.

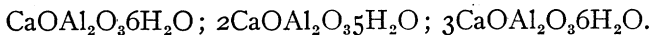
Fremy produced aluminates of the composition :



which hardened in water almost instantly. When mixed with sand, these aluminates became almost stone-like in character. Fremy thought the higher the aluminates were burnt the more hydraulic they were. Hence, he advised the burning of Portland cements to as high a temperature as possible, so as to fuse the aluminates and obtain the benefit of their maximum hydraulicity.

Michaelis fused a mass of the formula $3\text{CaOAl}_2\text{O}_3$ in a gas flame fed with oxygen, and found the powder to harden exceedingly well. The hardened mass was attacked neither by carbon dioxide nor water.

A mixture of $3\text{CaOAl}_2\text{O}_3$ thus fused and powdered set at once, but softened slowly under water. V. Lieven confirms the hydraulic activity of aluminates, but denies that they contribute to the permanent hardness of cements, since, according to him, they decompose into aluminum hydroxide, calcium hydroxide and calcium carbonate. The products on first hardening are :



Winkler also experimented with lime and ferric oxide, producing a mixture of eight equivalents of lime, one equivalent of potash and four equivalents of ferric oxide. This resulted after burning in a black, slightly clinkered mass, whose powder heated strongly in water and became friable. Heldt burnt together one equivalent of ferric oxide with eight equivalents of burnt marble, and obtained a vitrified mass, which when powdered and made up with water heated but slightly, and soon broke down to calcium carbonate and ferric oxide.

Michaelis was not at first successful in producing a fused or vitrified mass of calcium and iron, owing to a reduction of the oxide. In an oxidizing flame he obtained the compounds $3\text{CaOFe}_2\text{O}_3$ and $3\text{CaO}_2\text{Fe}_2\text{O}_3$ as fused bodies, which when powdered were red or dark brown in color. Made up with water the $3\text{CaOFe}_2\text{O}_3$ body heated appreciably, the $3\text{CaO}_2\text{Fe}_2\text{O}_3$ compound did not. In air they became tolerably hard, in water they decomposed.

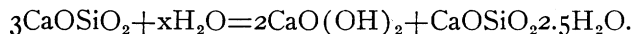
In regard to the function of magnesia, the earlier investigators disagree most decidedly. Fuchs produced a good cement of great hardness from talc; Rivot and Chatoney claim that magnesia behaves analogously to lime, hardening in water like the calcium compounds, but do not advise the use of magnesia, owing to its slowness of hydration,

which interferes with the hydration of any lime present. The alkalis, Fuchs says, have no influence upon the hardening.

The Work of Chatelier.—The synthetic work of Chatelier* may be summarized as follows:

Wollastonite, mono-calcium silicate, which is a mineral found in nature, is not hydraulic. The di-calcium silicate 2CaOSiO_2 , made by heating an intimate mixture of calcium carbonate and quartz, disintegrates spontaneously on cooling, which evidently is due to a molecular change. The tri-calcium silicate, 3CaOSiO_2 , he claims, cannot be obtained by direct synthesis. When made by heating silica with lime, more or less free lime always results. But it may be formed indirectly by crystallization from a magma of more fusible compounds of silica, alumina, lime and iron oxide. This compound is the basis of hydraulic activity in Portland cements. The mono-calcium aluminate CaOAl_2O_3 is almost infusible. It shows hydraulic activity. The di-calcium aluminate $(2\text{CaO})\text{Al}_2\text{O}_3$ is quite fusible and sets when made up with water quite rapidly. It shows, however, a great tendency to disintegrate after hardening.

The tri-calcium aluminate $(3\text{CaO})\text{Al}_2\text{O}_3$ is decidedly fusible and sets rapidly. The lime-iron compounds all slake with water, and are not hydraulic. According to Chatelier, hardened cement consists of hexagonal crystals of lime hydrate, surrounded by a white mass of needle-shaped hydrous mono-calcium silicate, $\text{CaOSiO}_2 \cdot 2.5\text{H}_2\text{O}$. The reaction of the hardening process corresponds to the following equation:



The Work of the Messrs. Newberry.—Of more recent investigations that of S. B. and W. B. Newberry** is one of the most extensive. In their article on "The Constitution of Hydraulic Cement," the title of which, however, is a misnomer, as the constitution of the hydraulic compounds was not touched upon, but only the range of composition was considered, a number of synthetic bodies were prepared. These were made by mixing dry, *without grinding*, almost pure silica alumina and calcium carbonate, moistening, and making into small pieces. These were burnt in a Fletcher pot furnace, fired with gasoline, provided with a Portland cement lining. The temperature reached in this furnace was probably quite high, but it is to be regretted that no attempt was made to measure it by means of Seger cones or other means.

These investigators endeavored to determine the presence of free lime by subjecting the pats made from the cements to the action of steam at 98°C . for four or five hours, after allowing the cement to stand over

**Ann. des Mines* 1887, 345.

***Journal Society Chemical Industry*, Vol. 16, No. 11.

night. The objection to this test is that it is not an accurate one, and at best but comparative. Messrs. Newberry prepared the following mixtures:

$(2\text{CaO})\text{SiO}_2$. The clinker was vitrified, translucent and crystalline. On cooling, fell to a powder. Some of the pieces were quenched in water and these yielded a good cement, which stood the hot test.

$(2.5\text{CaO})\text{SiO}_2$. Clinker white, somewhat vitrified. No sign of dusting. Pat showed very good setting quality, hardened slowly in water; decidedly hard after six weeks. Sound in steam test.

$(3\text{CaO})\text{SiO}_2$. Clinker shrunken, slightly sintered; no dusting. No heating on hydration. Pat rather soft at seven days, hard at six weeks. Sound in hot test.

$(3.5\text{CaO})\text{SiO}_2$. Clinker but slightly sintered; soft; no dusting. Pat set hard, but left glass, curved slightly, and cracked; became hard after several weeks in water. Sound in hot test.

In the following table the results of their tests have been arranged:

Silicates.

Formula.	Ratio, CaO to SiO_2 .	Composition.		Pat test.	Hot test.
		CaO.	SiO_2 .		
$[\text{2CaOSiO}_2]$	1.85	65.11	34.89	Set hard, hard 7 days, hard 6 weeks.	Sound; on glass hard.
2.5CaOSiO_2	2.33	70.00	30.00	Set soft, fair 7 days, hard 6 weeks.	Same.
3CaOSiO_2	2.80	73.68	26.32	Set soft, fair 7 days, hard 6 weeks.	Same.
3.5CaOSiO_2	3.27	76.56	23.44	Cracked, soft; hard 6 weeks	Same.

The lime alumina compounds were likewise investigated by these experimenters and the following mixtures prepared, which were also burnt at a high temperature:

$(2.0\text{CaO})\text{Al}_2\text{O}_3$ fused in direct heat, strongly clinkered in crucible; vitrified strongly. Set in a few seconds like plaster. The pat was hard, and on glass after six weeks. Hot test, on glass fairly hard, soft on inside.

$(2.5\text{CaO})\text{Al}_2\text{O}_3$ fused in direct heat, strongly clinkered in crucible; set quick. Pat off glass in one day; soft and cracked after six weeks.

$(3\text{CaO})\text{Al}_2\text{O}_3$. Semi-fused in crucible. Powder heats strongly with water. Pat cracked before putting in water. Disintegrated entirely in water. Hot test, curved and cracked soft.

In the following table their results are arranged :

Aluminates.

Formula.	Ratio, CaO to Al ₂ O ₃ .	Composition.		Pat test.	Hot test.
		CaO.	Al ₂ O ₃ .		
2.0CaOAl ₂ O ₃	1.10	52.38	47.62	Set quick, hard, sound six weeks.	Sound; on glass fairly hard.
2.5CaOAl ₂ O ₃	1.37	57.85	42.15	Set quick, curved and cracked.	Curved and cracked, soft.
3.0CaOAl ₂ O ₃	1.65	62.23	37.77	Set quick, curved and cracked.	Curved and cracked, soft.

The next question examined was whether the cement formula of Chatelier $x[(3\text{CaO})\text{SiO}_2] + y[(3\text{CaO})\text{Al}_2\text{O}_3]$ should not be modified to $x[(3\text{CaO})\text{SiO}_2] + y[(2\text{CaO})\text{Al}_2\text{O}_3]$, since the $(3\text{CaO})\text{Al}_2\text{O}_3$ showed such inferior qualities. By taking as the clay base, a kaolin and a silicious clay base, and using both formulas, it was found that the formula suggested by Messrs. Newberry produced a much better cement in each case. The effect of ferric oxide was also studied, and it was found that a mixture of $2\text{CaOFe}_2\text{O}_3$ fused to a black slag which, when ground, was brown in color, did not heat nor set in air or cold water. When placed in steam it hardened rapidly and did not crack on boiling.

A mixture of the formula $(3\text{CaO})\text{SiO}_2 + (2\text{CaO})\text{Fe}_2\text{O}_3$, containing 7 per cent. of ferric oxide, gave a cement setting slowly and becoming hard in 28 days. Sound in hot test and on glass. This shows that ferric oxide is able to promote the union of silica and lime similarly to alumina. Some mixtures containing both alumina and iron were prepared in which it was found that perfectly sound and satisfactory cements were produced. In one of these cements no lime was assigned to the ferric oxide; in the other two molecules of lime were reckoned for each molecule of the iron oxide, the percentage of alumina and iron being 4 to 3 respectively. In another mixture, with 4 and 3 per cent. of alumina and iron oxide, but figuring 3 molecules of lime to one of alumina, the resulting cement showed high tensile strength, but failed in the hot test. The alkalis in cement were found to be injurious in effect rather than beneficial.

Magnesium compounds were likewise studied, and it was found that when burnt at the highest white heat of the gas furnace the following results were obtained ::

MgOSiO_2 , hard semi-fused clinker, no hydraulic properties.

$(2\text{MgO})\text{SiO}_2$, well sintered, porous clinker; no cement properties.

$(3\text{MgO})\text{SiO}_2$, infusible clinker; hardened slowly in moist air, but turned to mud on placing in water.

The conclusions of these writers are summarized by them as follows:

"1. The essential constituents of Portland cement are tri-calcium silicate, with varying proportions of di-calcium aluminate. This composition may therefore be expressed by the formula $x(3\text{CaO} \cdot \text{SiO}_2) + y(2\text{CaO} \cdot \text{Al}_2\text{O}_3)$. From this formula it may be calculated that the correct proportion of lime, by weight, in Portland cement is 2.8 times the silica *plus* 1.1 times the alumina.

"2. Iron oxide combines with lime at a high heat and acts like alumina in promoting the combination of silica and lime. For practical purposes, however, the presence of iron oxide in a clay need not be considered in calculating the proportion of lime required.

"3. Alkalies, so far as indicated by the behavior of soda, are of no value in promoting the combination of lime and silica, and probably play no part in the formation of cement.

"4. Magnesia, though possessing marked hydraulic properties when ignited alone, yields no hydraulic products when heated with silica, alumina, or clay, and probably plays no part in the formation of cement. It is incapable of replacing lime in cement mixtures, the composition of which should be calculated on the basis of the lime only, without regard to the magnesia present."

Professor S. B. Newberry repeated part of these experiments in additional work published in 1902* which might be briefly summarized as follows:

He again reports having prepared 3CaOSiO_2 by mixing the finely ground materials dry, and heating the mixture to a white heat. It does not, however, harden readily. No direct chemical proof of the 3CaOSiO_2 is given. By fusing the mixture over the oxy-hydrogen blow pipe the 3CaOSiO_2 was found to be double-refracting, with rectangular cleavage, specific gravity 3.022, is constant in volume, hardens well. A mixture of calcium carbonate and silica, heated for two hours at a red heat, leaves some SiO_2 uncombined unless at least $2\frac{1}{2}$ molecules of CaO to one of SiO_2 are present. At a white heat the mono, di and tri-silicate mixtures become completely combined. The amount of water which a given Portland cement will take up chemically is a function of the mechanical conditions, porosity, etc. It may be as low as 10 or as high as 27 per cent.

On suspending finely divided calcium silicate in sufficient water to dissolve all the lime present, the residues are somewhat indefinite in composition, and continue to lose lime on prolonged action; they have, however, the following composition:

Tri-silicate (not fused), after 29 and 93 days, $3\text{CaO}_2\text{SiO}_2 \cdot 3\text{H}_2\text{O}$.

Tri-silicate (fused), 35 and 228 days, $2\text{CaOSiO}_2 \cdot \text{H}_2\text{O}$.

The di-silicate (quenched and dusted), did not change in composition and did not hydrate.

**Cement and Engineering News*, Nov., 1902.

The action of an amount of water insufficient to dissolve all of the lime present (100 cc. to 5g.) on the fused tri-silicate, for thirty days, followed by a treatment with sugar solution for 29 and 186 days, gives a residue approximately $3\text{CaO}_2\text{SiO}_2 \cdot 3\text{H}_2\text{O}$ and $3\text{CaO}_2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$.

The Work of Zulkowski.—Of special interest are also the results of the synthetic experiments of Zulkowski.* He prepared mixtures of various hydrolites, studied their behavior and found great difficulties in burning them, due to the high heats required and the contamination of the mixtures from the refractory lining. The first mixture prepared was the bi-calcium silicate, which, according to theory, should exist in two modifications, a hydraulic, active one, a basic metasilicate, obtained by rapid cooling or quenching, and an inert body produced on slow cooling. Zulkowski succeeded in producing some of the active variety and found it to harden satisfactorily, setting in three hours and becoming very hard in one month. The water content of the hydrate he found to be 4.06 per cent., and since the theoretical basic meta-calcium silicate contains 9.45 per cent. of water his specimen contained by calculation only $(4.06 \times 100) \div 9.45 = 42.9$ per cent. of the hydrolite. He did not succeed in producing a purer variety, and hence he resorted to the use of fluxes, using barium, boric acid and fluorspar. Since, however, these additions obscure the real properties of the mixtures, we cannot go further into the discussion of his elaborate results. In regard to the tri-calcium silicate, he denies its existence very strongly, basing his objection on the fact that such a compound would require silicon to have a valency of 6. However, Zulkowski made the attempt to produce it in a Seger kiln, but found that the apparently clinkered product broke down to dust. The burn lasted 10 hours. On making up with water it did not harden.

The dimagnesium meta-silicate produced by Zulkowski on heating for 8 hours at a white heat, set in 2 hours, and after two months in water was of moderate hardness. It was found to contain only 3.31 per cent. of water of hydration, showing an exceedingly slow reaction.

The di-calcium aluminate burnt to vitrification was found to set very rapidly in 2 to 3 minutes, showing distinct heating. After three months in water it showed an enormous hardness. The water of hydration found is shown by the following amounts:

	Per cents.
1 day.....	12.43
2 days.....	18.47
3 days.....	21.62
30 days.....	24.93

A pat which was two months in water contained 22 per cent. of water of hydration. The mono-calcium aluminate set in 2 minutes,

*Sonderabdruck aus der Zeitschrift, "Die Chemische Industrie." 1901.

and after three months in water showed extreme hardness. Its content of water was found to be 19.87 per cent.

A cement was now prepared with pure kaolin as a basis according to the formula: $2(2\text{CaOSiO}_2) + (2\text{CaO})\text{Al}_2\text{O}_3$.

The composition of this cement was thus:

	Per cent.
Silica.....	21.12
Alumina.....	18.61
Lime.....	58.89
Magnesia and alkalies.....	1.38

This cement, when powdered, set in 15 minutes, heating somewhat. After 90 minutes it was extremely hard, and after several months in water it was still harder. After 30 days it was found to show 17.05 per cent. of water of hydration. This checked reasonably well with the water of hydration calculated from the two separate mixtures previously prepared, the di-calcium meta-silicate and the di-calcium aluminate. By calculation this cement should contain 16.19 per cent. of water of hydration. This kaolin cement was of a pure white color and might serve as an example of a white cement. A temperature of cone 18 is said to be sufficient for its production.

One of Zulkowski's students also examined a commercial Portland cement of the composition:

	Per cents.
Silica.....	23.40
Alumina.....	6.07
Ferric oxide.....	2.51
Lime.....	63.87
Magnesia.....	0.97
Potash.....	0.80
Soda.....	1.22
Sulphur trioxide.....	14.5

which was a cement of excellent quality.

By calculation, according to Zulkowski's views, this cement contains:

61.89 per cent. di-calcium meta-silicate,
 12.14 per cent. di-calcium aluminate,
 4.35 per cent. di-calcium ferrate,
 14.22 per cent. calcium oxide,
 0.97 per cent. magnesium oxide.

This ought to contain accordingly 14.67 per cent of water of hydration. On hydration the di-calcium silicate splits off half of its calcium as calcium hydrate, the silica remaining as mono-calcium silicate, the alu-

minate and ferrate lose all of their lime, so that, together with the calcium oxide already free, 43.18 per cent. of calcium hydrate is formed.

In determining the water of hydration there was found after

	Per cent.
1 day.....	4.30
2 days.....	6.47
7 days.....	11.32
21 days.....	14.44
30 days.....	14.44

agreeing quite closely with the theory.

Finally Zulkowski pictures the formation of hydraulic cements as follows, assuming that the reaction starts with the ideal clay base, kaolin:

1. On the dehydration of the kaolin and expulsion of carbon dioxide a temporary product is formed by the replacement of the two molecules of water by two molecules of lime, thus, $2\text{SiO}_2\text{Al}_2\text{O}_3 \cdot 2\text{CaO}$.

2. Addition of another molecule of lime forming a more basic lime-alumina silicate $2(\text{CaOSiO}_2)$, CaOAl_2O_3 . The silicate is not a hydrolite, but the aluminate is, the lime going off as hydrate and the alumina also as hydroxide.

3. With increasing heat both the mono-calcium compounds change to di-calcium silicate and aluminate and all the lime beyond the amount necessary for this purpose remains as free lime.

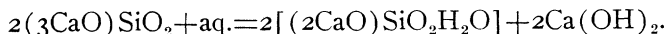
If for one molecule of pure kaolin in place of the 6 molecules of lime necessary only 5 molecules are taken dusting will take place.

The Work of Meyer.—Equally interesting are the results obtained by Meyer,* who followed in his experiments more closely the work of Chatelier. He prepared cements without alumina, using iron and manganese oxide as fluxes, and had no difficulty in producing tri-calcium silicate, which appeared in colorless crystals as found in ordinary cements. If the temperature is carried too high, white crystals will be found floating in the mass, corresponding to 3CaOSiO_2 . This must be the main hydraulic agent. No aluminates or ferrates are formed, as the alumina and iron must be united with the silicate.

The claim of Zulkowski that the silicate is present as the di-calcium meta-silicate is considered erroneous by Meyer, who claims that this compound could not exist together with free lime. At the same time Meyer does not believe that the tri-calcium silicate can be produced by direct synthesis, but must be prepared by crystallization from a fused magma. The presence of a meta-dicalcium silicate Meyer considers impossible, since, according to him, the tri-calcium silicate hydrates to $2\text{CaOSiO}_2 \cdot \text{H}_2\text{O}$, which loses half of the fixed water at 160°C ., while

*Meyer, *Tonindustrie Ztg.*, No. 144, 1902.

calcium hydrate loses its water at a much higher temperature. The fact that half of the fixed water escapes at 160° C. indicates that the molecule is a double one. The remaining water leaves at a much higher temperature. The process of hydration is represented by the following reaction:



DETERMINATION OF FREE LIME.

The attempts to accomplish the removal of free lime from the anhydrous as well as the hydrated cement are very numerous indeed, for it is fully realized by every investigator that if this could be accomplished the problem of the constitution of Portland cement would be cleared up. Various reagents for the extraction of the lime have been proposed, and we shall consider the methods proposed briefly in the following paragraphs:

The Work of Rebuffat.—Rebuffat* used for these purposes an aqueous sugar solution, which method, however, has been proven by Feret** to be erroneous, since the solution acts upon and decomposes the basic silicate. Michaelis has raised the same objection and claims that any results based upon such a solution must be wrong. The conclusions of Rebuffat must, hence, be accepted with considerable caution. In brief they are as follows.

He divides cements into two classes, viz:

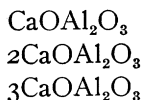
1. Cements of simple, compact structure, non-crystalline, derived from a mixture of calcium oxide, silicate, and aluminate. These comprise the hydraulic limes and quick setting cements.
2. Cements of crystalline structure derived from a combination of a crystalline mass, consisting of 2CaOSiO_2 and CaO and the calcium aluminate in various proportions—Portland cements and cements high in silica.

He assumes that the quantitative constitution of the different hydraulic cements after setting is the same. They are formed from a mixture of lime hydrate, hydrated calcium silicate, and hydrated calcium aluminates, with a slight quantity of accessory ingredients. The calcium silicate is the ortho-silicate— 2CaOSiO_2 . The quantity of water of hydration which is absorbed does not exceed $5\frac{1}{2}$ per cent., so that the hydrated compound has the formula $(2\text{CaOSiO}_2)_2 + \text{H}_2\text{O}$. In cements high in silicate the presence of a certain quantity of meta-silicate must be accepted. This does not hydrate, but reacts with the aluminates and forms double silicates of calcium and alumina. This fact is important, as it explains the resistance of cements to sea water.

**Gaz. Chim. Ital.* 1898 and *Tonindustrie Ztg.* 1901, No. 105.

**International Cong. for Testing Building Materials, Paris, 1890.

The calcium aluminate may have one of the following formulas:

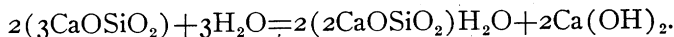


But unless there is an excess of lime or unless certain conditions of burning prevail, it seems that only CaOAl_2O_3 and $2\text{CaOAl}_2\text{O}_3$ should be considered.

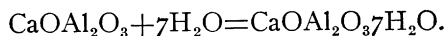
The quantity of water chemically fixed by hydration cannot be determined beforehand. The cements hydrate in different degrees according to whether they harden in pure or lime water. To this are due many peculiarities in setting.

In setting, the calcium ortho-silicate is hydrated to form $2(2\text{CaO SiO}_2) + \text{H}_2\text{O}$, which is followed by the hydration of the calcium aluminate. These two reactions take place in different phases for different cements.

With cements of crystalline structure, it must be assumed that the calcium ortho-silicate is found combined with CaO and the calcium aluminate in a definite crystalline condition. Portland cement in the hydrated condition contains but small quantities of calcium aluminate. This explains that in cements of a crystalline character the setting may be caused by the hydration of the calcium ortho-silicate according to the following reaction::



This is associated with the hydration of the aluminate, which in Portland cement consists mainly of mono-calcium aluminate and hydrates with seven molecules of water.



Rebuffat found that all the water of crystallization does not become free at low heat, but part is expelled at a bright red heat.

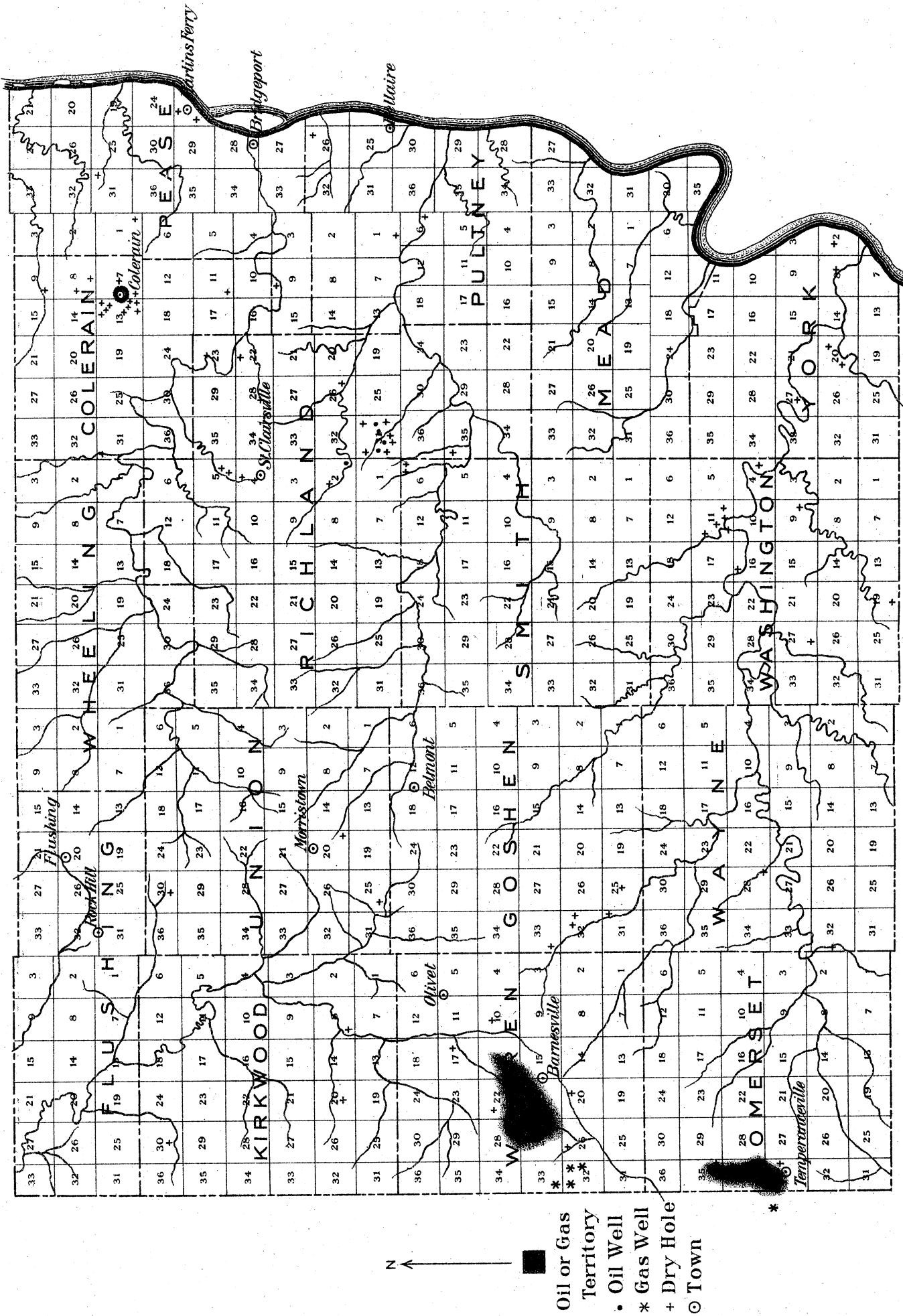
Other Investigators.—Dr. Tomei¹ treated hardened cement with an aqueous solution of ammonium chloride and found that the amount of lime thus dissolved decreased in amount after some time. He concluded from his experiments that the stability of the lime compounds increases with time, and that part of the silica from the sand of the mortar enters into combination with the lime.

In 1895, A. Hauenschild² treated a number of hydraulic cements with various solutions of ammonium salts and found that the salts did not permit of an exact determination of the lime compounds.

¹ *Tonindustrie Ztg* 1895, p. 177.

² *Ibid.*, 1895, p. 239.

MAP VII.



B. Steuer³ allowed hydrogen sulphide to act upon water in which finely powdered Portland cement had been poured. In this manner he extracted 44 per cent. of calcium oxide which he considered free lime, while the residue corresponded to the formula CaOSiO_2 .

S. Wormser and O. Spanjer⁴ used as reagent for the solution of free lime an alcoholic solution of aluminum chloride. They claimed to have proven that this solution (1 g. in 100 cc. absolute alcohol) does not decompose the silicates, but dissolves only free lime. The per cent. of CaO found to go in solution as such was 25, while in addition 20 per cent. of lime was found present as a highly basic silicate. They calculated, by means of their method, a content of 26.6 per cent. of free lime, and 18.65 per cent. of CaO , combined with 6.15 per cent. silica.

Dr. Hart* in the same year, by means of a 10 per cent. alcoholic iodine solution, found, he claims, 30.34 per cent. of free vitrified calcium oxide in Portland cement; the balance of the cement material he considers as ballast, as slag which does not harden; on hydrating, this vitrified lime hardens under water. He cites this free lime as a fine example of a body whose chemical energy is manifested, not by a thermal reaction, but by a mechanical development of energy. The reason why so much free calcium oxide is not injurious to the cement, he explains by saying that this lime is vitrified and crystalline. Vitrified, crystalline calcium oxide and the amorphous lime, though not distinguished analytically, are different physically. This argument is open to many objections, whose discussion here would lead too far.

HEAT REACTIONS.

Dr. Hart's work was supplemented, however, by thermo-chemical experiments, in which he determined the heats of neutralization of wolastonite CaOSiO_2 , artificial CaOSiO_2 , 2CaOSiO_2 , 3CaOSiO_2 , CaOAl_2O_3 , $2\text{CaOAl}_2\text{O}_3$, $3\text{CaOAl}_2\text{O}_3$. He determined the heats evolved for the anhydrous cement as well as for the hydrated and dehydrated cement which had been allowed to harden. The heat of neutralization of the hardened, not dehydrated cement should be higher than that of the clinker, since the former contains a considerable amount of free calcium hydrate. In Portland cement the heat of neutralization is lowered on hydration, while the heat evolved by the dehydrated cement is almost equal to that of the clinker. From this Dr. Hart concludes that from 30 to 34 per cent. of free lime must be present in cement.

³*Ibid*, 1899, p. 604.

⁴*Ibid*, p. 1785.

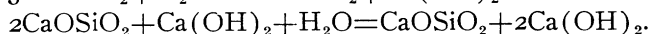
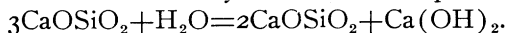
**Tonindustrie Ztg.* pages 659, 770, 853, 1899; 1900, p. 188.

Dr. Hart gives the heats of neutralization of the various silicates in the following table:

	As clinker.	Hydrated after 28 days.	Dehydrated.
	Calories.	Calories.	Calories.
Wollastonite	13.0	....	....
Artificial CaOSiO_2	234.7	187.5	....
2CaOSiO_2	325.0	326.0	327.3
3CaOSiO_2	270.1	266.0	276.5
CaOAl_2O_3	41.4	172.7	238.7
$2\text{CaOAl}_2\text{O}_3$	201.0	240.2	356.6
$3\text{CaOAl}_2\text{O}_3$	428.2	266.6	....

The question of whether Portland cement consists of compounds of silica with lime or whether it is simply a colloid mixture of decomposed clay and lime was attacked by Dr. W. Ostwald* from the thermo-chemical standpoint by determining the heats of solution in hydrochloric acid (5 grams cement in 500 cc. acid, specific gravity 1.06) using a beaker calorimeter. His results have shown that Portland cement must consist essentially of compounds of lime and the constituents of clay.

Another interesting more recent investigation was carried on by W. Richter** who found that Portland cement did not react with phenol-phtalein, but did as soon as ignited calcium oxide was added. The latter did not slake like ordinary lime, but broke down to a granular powder. With water the ignited lime set like cement and showed but a slight rise in temperature; it stood the boiling test and reacted with phenol-phtalein. Richter concludes, that all the lime in cement is combined. He claims that there can be no aluminate of lime, as calcium aluminates were found to react with phenol-phtalein. He further prepared a tri-calcium silicate not reacting with phenol-phtalein. The boiling test he does not consider a sufficient criterion for the presence of free lime. The di-calcium silicate he found to possess slight cementing qualities, but it did not stand the boiling test. On grinding the di-calcium silicate with crystalline calcium oxide, a cement was obtained which hardened like a tri-calcium silicate cement. Richter thinks that the hydration reaction proceeds as follows:



In 1899 Dr. Michaelis* published a startling theory which contradicted all the previous assumptions. He claimed that the hydraulic hardening is a combination of chemical and physical processes. For

**Tonindustrie Zeitung*, 1888, No. 46.

***Ibid*, 1903, No. 120.

the main constituent, the hydro-silicate of lime crystallization cannot be proven notwithstanding the claims of Chatelier and others. The process of hardening depends upon an increase in volume on the part of some of its constituents, or the formation of gelatinous silicic acid. On letting a large quantity of water act on Portland cement, the volume of the latter is changed to a colloid mass occupying 33 times the original volume. On treating cement with lime water, the volume is increased 21 times. Even quartz, when treated with milk of lime, is converted into the colloid variety in which it is greatly increased in volume. The same is true of alumina and iron. Michaelis cites the manufacture of sand brick, by the action of calcium hydrate on crystalline silica as a proof of his theory. His claims, however, have found no approval by most of the cement chemists and investigators.

Of late, since the study of colloids has assumed new importance, his claims deserve more attention than they have received so far. It cannot be denied that colloidal conditions have something to do with the hydration and hardening of cements.

SUMMARY OF THE CONTENDING VIEWS.

It might seem difficult to draw general conclusions from the array of theories presented to the reader in the foregoing paragraphs, but the conditions are not as complex as they seem if we put our main reliance on microscopic evidence and do not attempt to write precise structural formulas. Portland cements are basic slags produced by vitrification, belonging to the subsilicate group, with the tri-calcium silicate as the main hydraulic factor, assisted by certain calcium alumina compounds which are spinel-like in character or more basic. The main silicate crystallizes out from a more fusible magma, enough of which must be present to produce solution, just as in a porcelain body the fluxes, feldspar and lime have the power to bring into fusion comparatively large quantities of the refractory materials, like kaolin and flint. The percentage composition of the cement requires certain, but by no means narrow, limits of lime and silica, in order to produce a sufficient amount of hydrolite, yet not too much, as otherwise the cement would require too high a temperature for vitrification, since not enough of the magma could be produced at lower temperatures. In nature the only mineral we know as approaching the type of the sub-silicate of an alkaline earth is chondrodite, $Mg_8Si_3O_{14}$, which, however, invariably carries iron and fluorine.

The different stages of the Portland cement reaction may be illustrated by considering the components of the raw mixture. It is made up of calcium carbonate, clay substance, quartz (more or less fine), feldspathic and iron carrying minerals, like mica, augite, hornblende, etc.

1. At about 900° C. the chemical water of the clay substance is expelled as well as the carbon dioxide of the calcium carbonate.

2. At the same temperature the chemical water is replaced by lime forming with the clay substance Al_2O_3 , $2SiO_2$, $2CaO$.

3. At about 1000° C. lime combines with the fine grained free silica, leaving, however, much free lime in excess. The mass now is porous, and when made up with water takes up the latter eagerly by capillary attraction, so that the hydration takes place easily. We now have virtually a Roman cement, setting rapidly and corresponding to the first hydraulic maximum of the natural cement curve. This reaction is essentially pozzuolanic in character.

4. Rising beyond 1000° up to 1100° or higher, the fluxing constituents begin to act, consolidating the mass, more free silica is taken up by the lime, so that we have probably compounds corresponding to the bi-calcium silicates. The hydraulicity has been largely destroyed; second minimum of Roman cement curve.

5. As the temperature rises still higher between 1200° and 1450° , depending on the amount of fluxing materials present, vitrification takes place rapidly within a short temperature interval and an exothermic reaction takes place, corresponding to the production of the subsilicate. We may represent this process to ourselves by supposing the fusion of an iron—alumina—calcium silicate which dissolves more and more lime until the basic silicate crystallizes out on cooling. Like all calcareous bodies the magma fuses with great rapidity, accounting thus for the short time required for the operation. The amount of heat evolved in the reaction has as yet not been calculated accurately, which may be readily understood considering the great experimental difficulties. We can readily understand that the clay substance and feldspathic matter enter readily into the reaction, but the combination between the quartz and lime is not so easily accomplished.

RESEARCHES MADE BY THE WRITER.

For the purpose of observing just how the lime combines with the quartz, and at what temperatures, mixtures of silica and calcium carbonate were ground together intimately, burnt in a dental furnace, fired with gasoline gas and the temperature measured by means of the Chatelier pyrometer. The resulting products were sealed in perfectly dry bottles and the heats of hydration determined by means of the calorimeter. This instrument, as shown by the cut (Figure 21), was made at the laboratory and served the purpose for which it was intended quite well. The thermometer, divided into 1-50th of a degree Centigrade, could be read without difficulty accurate to 1-100th by means of a small telescope. The thermometer was calibrated and the water equivalent of the instrument calculated repeatedly. The stirrer consisted of a thick copper wire with a ring at the lower end, a vertical motion being imparted to it by means of a string running over a pulley. Though the construction of the apparatus is open to several criticisms, it nevertheless, on testing, gave close results with standard thermal determinations, showing an accuracy beyond that really needed in this work, inasmuch as the influences tending to produce irregularities during the burning were far more numerous. The corrections made for radiation were carried out according to the

method given in "Physical-Chemical Measurements" by Ostwald and Luther. No correction was made for heats of solution. The samples, having been ground in a porcelain ball-mill, were burnt in a Denver white-clay crucible. The amount of sample used varied from three to five

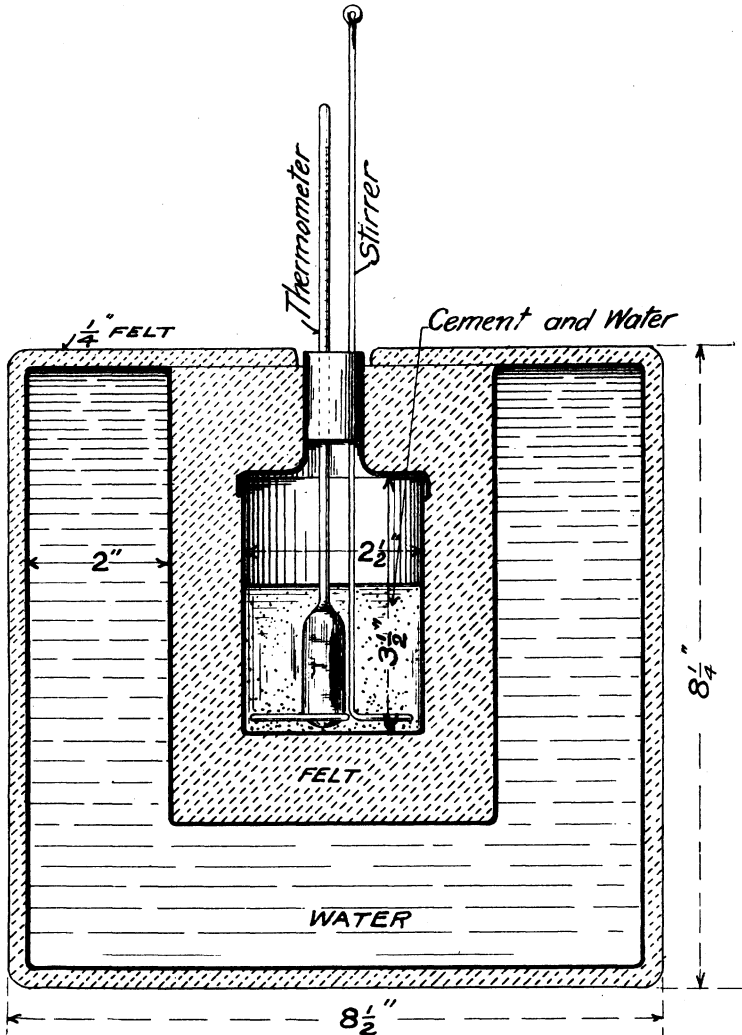


Fig. 24. Calorimeter, for measuring heats of hydration of cements.

grams, and an excess of water was used, 100 cc. The calorimetric work was carried on in a basement room, excessive variations in temperature being thus avoided. Whenever any result was doubtful, a check determination was made.

The ground quartz (flint) showed the following mechanical analysis:

	Per cent.
Residue on 120 mesh sieve.....	1.40
Residue on 150 mesh sieve.....	2.36
Residue on 200 mesh sieve.....	1.06

Grains, average diameter 0.00211 inch.....	24.74
Grains, average diameter 0.00086 inch.....	17.84
Grains, average diameter 0.00041 inch.....	9.30
Dust below these sizes.....	43.30

The results of these experiments are given in the table below. It was a disappointment to find the results were not as concordant as would be desired, but showed variations that cannot be explained satisfactorily. This was the more annoying since considerable work and time was given to this investigation.

Formula of mixtures.	Calcium oxide per cent.	Silica per cent.	Temperature of burn °C.	Calories per gram.	Equivalents of calcium oxide "uncombined,"	Approximate formula of "combined" lime compound.
1.0CaOSiO ₂	48.27	51.72	600	....	....	
"			700	2.98	....	
"			800	1.70	....	
"			900	7.34	....	
"			1,000	19.85	0.02	0.98CaOSiO ₂
"			1,170	2.76	....	CaOSiO ₂
1.5CaOSiO ₂	58.34	41.66	700	10.71	....	
"			800	15.08	....	
"			900	67.88	....	
"			1,000	57.56	0.48	1.02CaOSiO ₂
"			1,100	2.76	0.03	1.47CaOSiO ₂
"			1,170	1.19	....	1.50CaOSiO ₂
2.0CaOSiO ₂	65.11	34.88	700	1.59	....	
"			800	50.00	....	
"			900	30.37	....	
"			1,000	2.50	....	1.97CaOSiO ₂
"			1,100	1.20	0.03	2CaOSiO ₂
"			1,170	0.79	....	2CaOSiO ₂
2.5CaOSiO ₂	70.00	30.00	700	7.54	....	
"			900	29.37	....	
"			1,000	73.46	0.95	1.55CaOSiO ₂
"			1,100	14.26	0.19	2.31CaOSiO ₂
"			1,170	6.80	0.09	2.41CaOSiO ₂

It is quite evident from the results obtained in this work as well as from other considerations that the heat of hydration of the calcium oxide present in these silicates cannot be used to approximate the amount of uncombined lime. In some manner the lime becomes "dead" burnt and does not hydrate as we should expect, analogous to the "dead" burnt limes in which a few per cent. of silica seem to take away from the time its tendency to slake rapidly. The *modus operandi* of this process cannot be followed without further investigation. The method proposed by some to determine the lime content of a limestone by igniting it and determining its hydration value hence does not promise to be a satisfactory test. In this connection it might be noted that cements with a silicious clay base, though very high in lime, show but a low heat of hydration. One fact, at least, was brought out quite clearly, namely, that silica does lower the temperature of the decomposition of calcium carbonate quite decidedly.

For purposes of comparison it might be well to quote the heats of hydration obtained by heating a crystalline limestone, 99.5 per cent. calcium carbonate, at different temperatures:

Temperature.	800° C.	900° C.	950° C.	1000° C.	1050° C.	1100° C.	1200° C.
Calories per gram...	34	175	257	260	252	254	247

In addition, these silicates were made up in water and allowed to harden in moist air for forty days, but practically all of them possessed but slight cementing qualities. In water most of them showed but a superficial hardness. Another experiment was decided upon in endeavoring to ascertain something in regard to the attack of lime on free silica. This was carried out by grinding together finely ground quartz, the same which was used in the preceding experiments in the proportion of 0.25CaOSiO_2 , = 18.9 parts of calcium oxide, and 81 parts of silica, igniting the mixture at different temperatures, and determining the residue, insoluble in hydrochloric acid and sodium carbonate solution. It was thought that in this way the lime was bound to come in contact with all the silica it could combine with at the different temperatures. These results are shown in the following tabulation:

Temperature °C.	Per cent. soluble silica.	Per cent. available CaO.	Sum of per cents. soluble silica plus available cal- cium oxide.	Per cent. car- bon dioxide.	Formula.
800	5.94	8.94	14.88	6.60	CaO, 0.7SiO ₂
900	6.44	16.40	22.84	1.30	CaO, 0.36SiO ₂
1,100	17.11	18.04	35.15	....	CaO, 0.877SiO ₂
1,200	22.10	18.04	40.14	....	CaO, 1.14SiO ₂
1,300	22.73	18.04	40.77	....	CaO, 1.18SiO ₂

At 800° apparently all of the free calcium oxide has combined with silica, while at 900° there is evidently some lime uncombined, so that the formula appears distorted. It is evident that the lime has united with no less silica than at 800°, but more calcium oxide is available than at the latter temperature. This is indicated also by the decided caustic property of this mixture. The best index of the activity of the lime is the amount of silica rendered soluble, especially if for 800° and 900° the carbon dioxide is eliminated by calculation which will make the soluble silica 6.36 and 6.52 per cent. respectively. The mixtures at 800° and 900° showed caustic properties, especially the 900° sample, while those of the other samples were lumpy and not noticeably caustic.

It is quite evident that the action of lime upon finely ground free silica is reasonably well represented by these experiments, and it appears that at the highest temperature employed, 1300° C., less than one molecule of lime is required to render soluble or available for combination one molecule of free silica, the proportion being 0.847 molecule of calcium oxide to one molecule of silica. This throws additional light on the Roman cement reaction, and explains why such cements may be so low in lime, the function of the latter being simply the "unlocking" of the inert quartz, and the work also indicates that there should be no difficulty in assimilating the quartz of clays, provided the latter is ground fine enough, so that it is not absolutely necessary to depend upon naturally fine clays. The practice of shipping naturally fine clays considerable distances is hence not a necessity, if sand or sandstone in any shape is available. On the other hand it encourages the use of silicious clays in preference to clays comparatively high in alumina.

It must also be realized that in a cement the attack of lime on silica is much more vigorous owing to the formation of a more fusible calcareous magma in which silica is bound to be quite soluble.

CHAPTER VI.

THE COMPOUNDING OF PORTLAND CEMENT MIXTURES.

In the selection of the raw materials the following factors must be considered :

THE CLAYS.

1. The clay must have a percentage ratio of silica to alumina of from 3:1 to 4:1. A clay should be found, if possible, which is naturally fine ; but if such a material cannot be found, either a coarse clay of the proper composition must be selected and ground fine, or an addition of ground sand or sandstone must be given a more aluminous but otherwise suitable clay.

In examining many Portland cements this point seems to be the chief difficulty with a number of brands. Owing to the high content of alumina, the cement not only sets too fast, but also shows an inherent weakness. Matters are made still worse by the addition of gypsum, which is a grave source of deleterious influences. At the same time, the clay should not be too silicious, but should lie between the above limits. The sum of the silica and alumina percentages in the hydrous clay should not exceed 87 per cent., thus leaving at least 13 per cent. for combined water and fluxes like ferric oxide, potash and soda.

2. The clay must not contain so much magnesia that the magnesia content of the cement rises above 3 per cent.

3. The clay should contain at least 3 per cent of ferric oxide, but not sufficient to raise the ferric oxide content of the cement over 4 per cent.

4. The clay should be low in sulphur and should not contain more than 1 per cent. of sulphur in any form.

5. The material should be free from any irregularly distributed matter, be it concretionary nodules of ferrous carbonate, calcium carbonate as found in the older sedimentary clays, or lumps of these or similar minerals as found in glacial clays.

Examples of how these considerations are neglected might be cited in considerable number, it having been the writer's task to examine numerous Portland cements. In one case a new plant used a clay of the following composition for its clay base :

	Per cent.
Silica.....	63.26
Alumina.....	22.70
Ferric oxide.....	5.20
Loss on ignition.....	6.52
	97.68

Ratio $\text{SiO}_2 : \text{Al}_2\text{O}_3 :: 2.78 : 1$

This mill was in operation for a number of months, but did not succeed in burning satisfactory cement. The heavy financial losses caused the plant to pass into other hands. There is no reason whatever to believe why, with an addition of free silica in some shape, the clay would not have produced a good cement.

Professor Edward Orton, Jr., in investigating certain limestone materials for Portland cement purposes found that the alumina was already high enough, while the silica required an increase. This he introduced in the form of finely ground sandstone, instead of the clay usually employed. The cements resulting from this mixture proved slow setting, requiring no addition of gypsum, but after 28 days showed an extraordinary strength, about 20 per cent higher than the best commercial cements.

Blaese* was compelled to work a clay of the composition:

	Per cent.
Silica.....	58.19
Alumina and ferric oxide.....	26.11
Lime.....	0.78
Magnesia.....	2.41
Loss on ignition.....	6.69
	94.18

The cement in spite of an addition of 2 per cent. of gypsum set in 2 to 3 minutes and showed decided "blowing" tendencies, so much, in fact, that barrels of cement were bursted, due to the expansion, in spite of the fact that a series of compositions was made so as to determine the best mixture. In this difficulty, this chemist added sea sand to the clay and succeeded in producing a cement of excellent quality. However, it is interesting to note that an addition of 0.5 per cent. of fluorspar to the raw mix also produced a good cement. This last fact does not help out the statement made above nor does it tend to refute it.

Prof. E. D. Campbell,** of the University of Michigan, has likewise found that lean clays, high in silica, are safer than aluminous clays.

In examining a clay analysis it is always to be recommended that the formula be calculated from it on the basis that alumina is taken as unity.

**Tonindustrie Ztg.* 1896, No. 1.

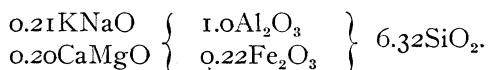
***Journal Amer. Chem. Society*, 1902, No. 10.

In this manner the mineral character of the clay becomes at once apparent. This, of course, is done by dividing the percentages of the constituents, silica, alumina, ferric oxide, lime and magnesia by the respective molecular weights, and then dividing each quotient thus obtained by the alumina quotient. This will make the alumina equivalent equal to unity.

A clay of the composition:

	Per cents.
Silica.....	63.73
Alumina.....	17.17
Ferric oxide.....	5.85
Lime.....	0.58
Magnesia.....	0.97
Potash.....	2.33
Soda.....	0.67
Combined water.....	4.90
	94.00

would thus have a formula corresponding to:



This tells us at once that this clay contains at least 4.32 molecules of free silica. Since the limits of silica to alumina given are 3:1 and 4:1 expressed in parts by weight, or percentages, they can also be expressed in molecular proportions in which the limits are: 5 molecules of silica to 1 of alumina and 6.66 silica to 1 alumina.

The limit set for the sum of the silica and alumina provides for fluxes which are necessary to promote the formation of an easily fusible magma and especially for a liberal amount of ferric oxide. The lower the fusing point of this magma, the more readily will the cement mixture vitrify and the lower will be the cost of burning.

As to the magnesia limit, much has been claimed pro and con, and the last word in this matter has not been said. Dyckerhoff probably has done more work than any one else in this respect, and it is his opinion that magnesia is a dangerous ingredient, if present in large quantities, owing to its slower hydration, which takes place when the calcium compounds have already become hardened, thus causing cement to expand unduly and destroying its structure more or less.

Ferric oxide, if present in not too great a quantity, is a desirable fluxing ingredient. Sulphur compounds are undesirable, since they form either compounds of lower oxidation, which on the hydration of the cement oxidize to sulphates with increase in volume, or, if already oxidized or oxidized in the kiln, take away as much lime from the silica as is necessary to form calcium sulphate, thus lowering the content of available lime. Calcium sulphate in itself is an undesirable ingredient

owing to its solubility in water, 1 part of anhydrous sulphate being soluble in 488 parts of water at 18° C. This apparently slight solubility after all is not to be neglected, especially since its solubility is increased most decidedly by the presence of other salts like sodium chloride, calcium chloride, etc. Thus at 21.5° C. a 3.5 per cent. solution of sodium chloride can dissolve 0.674 grams of gypsum for each 100 cubic centimeters.

LIMESTONE AND CALCAREOUS MATERIALS.

1. These should be fine grained and uniform in composition and structure.
2. The magnesia should be low enough so that in the cement a content of 3 per cent. of magnesia is not exceeded.
3. The alumina content should not be high enough to disturb the proper silica-alumina ratio in the cement.
4. The content of ferric oxide must not be so high as to increase the amount of ferric oxide in the cement beyond 4 per cent.
5. It should be low in sulphur and free from concretionary iron sulphide.

In the consideration of calcareous materials, the most important question is that of the magnesia content, as the restricting clause in regard to the magnesia rules out many otherwise excellent materials. In many cases the limit of magnesia is exceeded but slightly and it seems a pity that such materials should be rejected. The fact is that it is unjust to throw out a material on account of one or two per cent. of magnesia in excess over the three per cent., as many tests have shown that a magnesia content even up to 7 per cent. in an otherwise well proportioned cement has no deleterious influence. It might be well to cite some investigations covering this point. Dyckerhoff's elaborate experiments, it is true, condemned magnesia. His work included the duplicate testing of various contents, both in regard to the tensile strength for periods up to five years, and the measurement of the increase in volume in terms of the linear expansion of a bar of cement 100 mm. long, made by careful micrometer measurements. The results obtained by him are summarized in the curves on pages 227-9.

Meyer, on the other hand, denies most emphatically that magnesia is a dangerous constituent. Blaese allows as much as 10 per cent. of magnesia. Tetmayer reports two vitrified cements of the analysis shown in table on page 230, as having stood the tests for constancy of volume.

The tensile and crushing strength expressed in kilograms per sq. cm. were found by him as given in the second table on page 230.

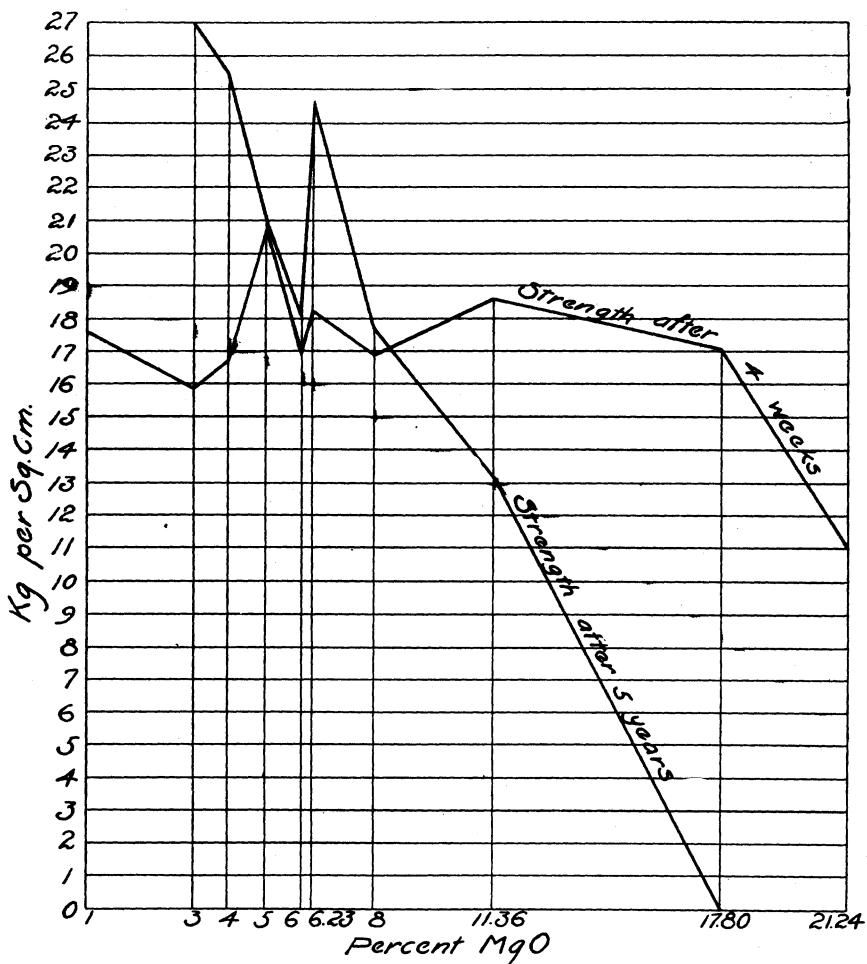


Fig. 25. Dyckerhoff's experiments on magnesia, showing tensile strength of high magnesia cements deteriorating with age.

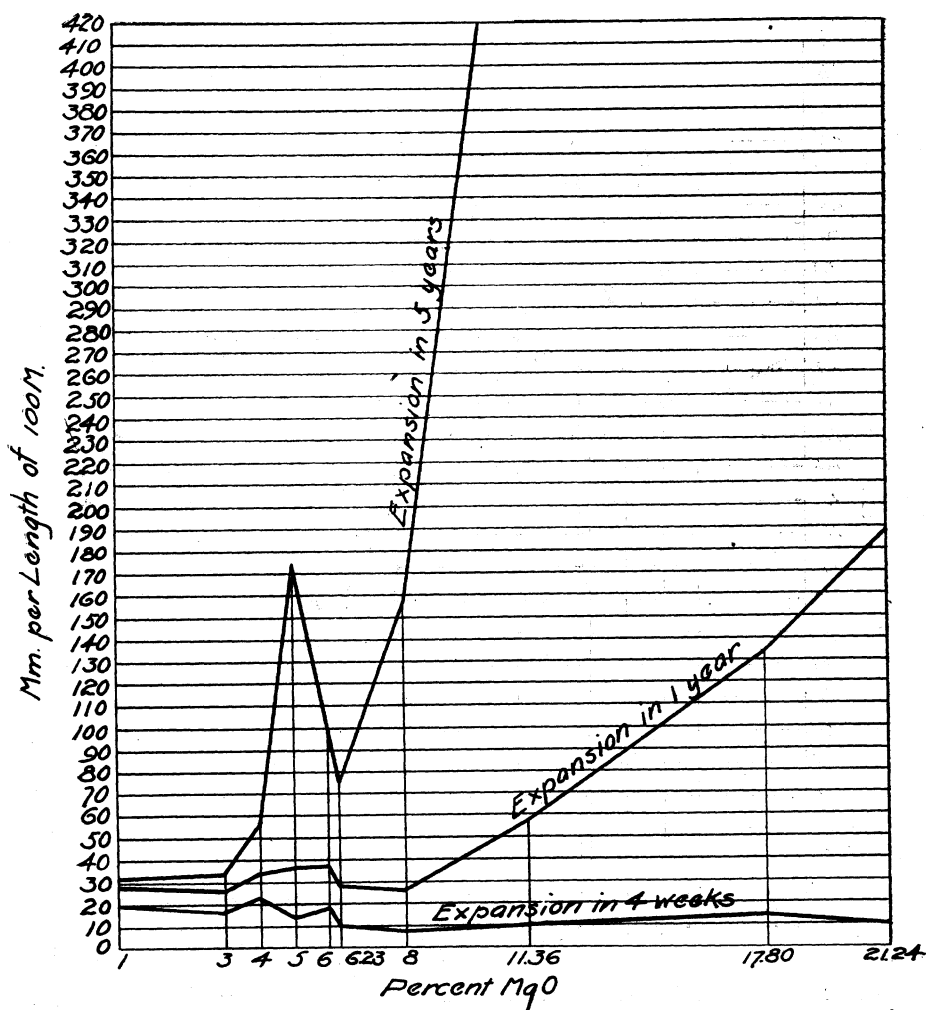


Fig. 26. Dyckerhoff's experiments on magnesia, showing expansion of high magnesia cements increasing with age.

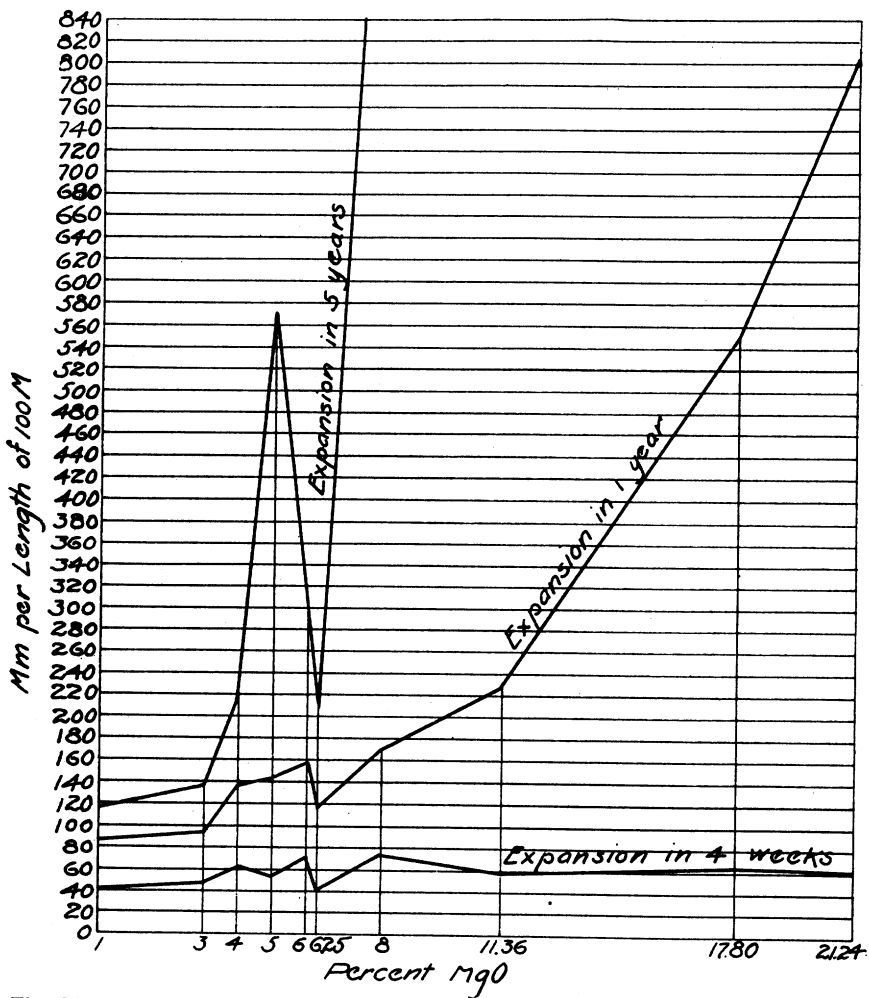


Fig. 27. Dyckerhoff's experiments on magnesia showing expansion of high magnesia cements increasing with age.

Composition of Two Vitrified Cements, by Tetmayer.

	Per Cents.	
	A.	B.
Silica.....	17.06	19.92
Alumina.....	5.28	7.01
Ferric oxide.....	3.07	2.73
Lime.....	48.45	35.29
Magnesia.....	17.28	8.39
Calcium sulphate.....	1.85	2.43
Loss on ignition.....	6.36	4.57

Tensile and Crushing Tests of Two Vitrified Cements, by Tetmayer.

Number.	Kind of test.	28 days.	1 year.	2 years.	3 years.	4 years.	5 years.	6 years.	8 years.	10 years.
A	Tensile strength	20.1	45.6	39.0	39.1	43.7	38.8	41.0	44.1	43.4
	Crushing strength	118.9	231.6	293.8	406.2	393.8	379.0	455.6	421.0	413.8
B	Tensile strength	33.5	57.9	57.3	60.5	68.0	60.3	60.4	64.8	63.5
	Crushing strength	207.6	363.8	.....	.....	372.8	.....	581.6	.....	614.7

In 1893 Kawalewsky made an extensive report on vitrified magnesia cements which after ten years were still found to be in excellent condition and showing great strength.

Golinelli in 1895 reported a carefully arranged series of tests with magnesium Portland cements containing an average of 26 per cent. of magnesium oxide and corresponding to the ratio

$$\frac{\text{CaO} + \text{MgO}}{\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3} = 2.06.$$

The silica-alumina ratio maintained was 3. These cements possessed most excellent strength and were entirely constant in volume. This investigator came to the conclusion that magnesia may be substituted for lime. On the other hand, it cannot be denied that some high magnesia cements have given trouble in practice, as a number of well authenticated cases are on record. This, together with the consideration

of the character of magnesia, its slow hydration, must lead to the general conclusion that dolomitic Portland cements are found to show two distinct rates of hydration, one due to the hydration of the lime compounds, the other due to the magnesium reactions.

Magnesia is active only at lower temperatures, and its rate of hydration is the slower the higher the compound has been burnt. But since two hydrations, a rapid and a slow one, cannot take place in a cement without injuring the structure, we must conclude that the cement should not contain enough magnesia to exert any appreciable influence. However, a content of magnesia up to 5 per cent., according to the experiments made so far, has proven harmless.

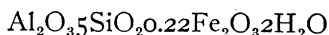
CALCULATION OF PORTLAND CEMENT MIXTURES.

For the calculation of the necessary amounts of clay and lime carrying material we have several available methods which we shall discuss briefly.

The Chatelier Formula.—American cement chemists make extensive use of the limiting Chatelier formula modified by Newberry:

$$x(3\text{CaO} + \text{SiO}_2) + y(2\text{CaO} + \text{Al}_2\text{O}_3).$$

Let us assume we have a clay of the formula:



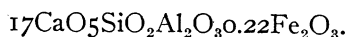
and, say, a pure limestone. We would have then the formula:

$$3x\text{CaO} + x\text{SiO}_2 + 2y\text{CaO} + y\text{Al}_2\text{O}_3, \text{ or} \\ (3x + 2y)\text{CaO} + x\text{SiO}_2 + y\text{Al}_2\text{O}_3.$$

But the clay contains 5 molecules of silica and 1 of alumina and the required molecules of calcium oxide will be:

$$(15 + 2) = 17\text{CaO}.$$

We find, hence, that the values x and y are the co-efficients of the molecules of silica and alumina in the clay. The formula of the cement is then:



The sum of the molecular weights of the clay formula is:

$$5\text{SiO}_2 + \text{Al}_2\text{O}_3 + 0.22\text{Fe}_2\text{O}_3 + 2\text{H}_2\text{O} = 473.2.$$

Therefore the limestone and the clay must be mixed in the ratio of 17×100 (molec. weight of calcium carbonate) $= 1700 : 473.2$, or for each part by weight of the clay $1700 \div 473.2 = 3.59$ parts of limestone must be taken.

We can, however, attack the problem from another standpoint, making use not of the formula, but of the percentage composition of the clay, which according to the above formula would be:

	Per cents.
Silica.....	63.40
Alumina.....	21.55
Ferrie oxide.....	7.44
Chemical water.....	7.61

The limiting formula $x(3\text{CaOSiO}_2) + y(2\text{CaOAl}_2\text{O}_3)$ can at once be translated into terms of parts by weight; since 3 molecules of calcium oxide are required for one of silica, we can say that $3 \times 56 = 168$ parts by weight of lime are needed for $1 \times 60 = 60$ parts of silica, or for one part of silica 2.8 parts of calcium oxide are required. In terms of the carbonate $(3 \times 100) \div 60 = 5$ parts are needed for one part of silica. Likewise we find that one molecule of alumina requires 2 molecules of lime, and hence one part of alumina must have 1.1 part of lime, or $200 \div 102 = \text{nearly two}$ parts of carbonate. The calculation now becomes very simple:

63.40 parts of silica demand $63.4 \times 5 = 317.09$ parts of carbonate.

21.55 parts of alumina demand $21.55 \times 2 = 43.19$ parts of carbonate.

360.28

100 parts of clay demand hence 360.28 parts of carbonate or 1 part must have 3.6 parts of the limestone, which is practically the same as the ratio obtained in the first problem.

The Limitations of the Chatelier Formula.—The Chatelier formula does not give entire satisfaction, however. For instance, taking the formula



we find the percentage composition to be:

	Per cents.
Lime.....	68.54
Silica.....	21.60
Alumina.....	7.34
Ferrie oxide.....	2.53

It will be noticed that the content of lime is higher than that of the average Portland cement. We assumed, however, that no fluxes were present; in using a clay with other fluxes like potash and soda the percentage of the calcium oxide would be reduced somewhat. This is due to the fact that the formula used is an ideal one, which requires ideal conditions of blending, that is, perfect pulverization which cannot be obtained in practice. However, it might be perfectly feasible to produce a

cement of this composition in the rotary kiln. The writer had no difficulty in burning such a cement without resorting to high temperature test furnaces. There is, however, some difficulty in keeping this up continually, since the high temperature would make the burning more expensive, the kiln linings subject to greater deterioration, and would increase the practical difficulties in operating the kiln. In addition, owing to the invariable fluctuations in the fineness of grinding, this high lime content would make longer storing necessary, which would likewise raise the cost. It might yet be mentioned that the above cement vitrifies thoroughly at about 1400°C .

Things become more serious, however, when we use a clay with a higher content of silica, say with the formula $\text{Al}_2\text{O}_3.6.66\text{SiO}_2.0.30\text{Fe}_2\text{O}_3.2\text{H}_2\text{O}$, which is by no means unusual or arbitrary. In fact, there are many clays which show a much higher molecular proportion of silica. Since we know the lime content of the cement to be a function of x , the number of the silica molecules in the clay, it is bound to rise with the silica content of the clay. This clay, hence, would make a cement of the following composition:

	Per cents.
Lime.....	69.83
Silica..	21.95
Alumina.....	5.60
Ferric oxide.....	2.63

The sum of the lime and silica percentages is hence 91.78, which indicates that the fusible magma whose function it is to start the vitrification is very small in amount, not sufficient to bring about vitrification at temperatures within practical reach. This is, of course, shown still more strikingly by more silicious clays, so that no amount of fine grinding could produce a good cement at the temperatures practically obtainable. The formula

$$x(3\text{CaO} + \text{SiO}_2) + y(2\text{CaO} + \text{Al}_2\text{O}_3).$$

is therefore inherently wrong when applied indiscriminately in practical work, and must be corrected either by a change in the molecular proportions or by the use of a constant for the various degrees of acidity of the clays.

Experiments on the Use of Different Formulae.—In order to study the effect of the use of different formulas in the dry preparation of Portland cements, the writer made up synthetic mixtures of kaolin, fine ground quartz, calcium carbonate and ferric oxide in quantities of about 20 pounds of raw mixture, grinding the materials together in an iron ball-mill for five hours. The iron oxide content was intended to be kept at about 3 per cent. These cements were then made up in five series of the following formulæ: $(3\text{CaO})\text{SiO}_2$, $(2\text{CaO})\text{Al}_2\text{O}_3$; (2.9CaO)

SiO_2 , $(2\text{CaO})\text{Al}_2\text{O}_3$; $(2.8\text{CaO})\text{SiO}_2(2\text{CaO})\text{Al}_2\text{O}_3$; $(2.7\text{CaO})\text{SiO}_2(2\text{CaO})\text{Al}_2\text{O}_3$; $(2.6\text{CaO})\text{SiO}_2$, $(2\text{CaO})\text{Al}_2\text{O}_3$.

Each series again was made up of five members, in which the ratio of clay substance to free silica, which is also expressed by the silica-alumina ratio, was made to vary. The following ratios were employed: 1.2, 1.9, 2.4, 3.1, 4.1.

The compositions of these cements are tabulated as follows:

Number.	Calcium oxide per cent.	Silica per cent.	Alumina per cent.	Ferric oxide per cent.	Magnesium oxide per cent.	Ratio, $\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$ by per cents.	Ratio, $\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$ by molecules.	Formula.
1	64.15	17.27	14.25	3.09	1.30	1.21	2.20	$(3\text{CaO})\text{SiO}_2(2\text{CaO})\text{Al}_2\text{O}_3$
2	65.93	19.55	10.30	2.87	1.34	1.90	3.22	
3	66.23	20.82	8.64	2.93	1.35	2.41	4.24	
4	66.98	21.68	7.04	2.95	1.36	3.08	5.23	
5	68.16	22.23	5.40	2.86	1.39	4.12	7.00	
6	63.83	17.68	14.47	2.69	1.30	1.22	2.07	$(2.9\text{CaO})\text{SiO}_2(2\text{CaO})\text{Al}_2\text{O}_3$
7	65.73	19.88	10.28	2.83	1.34	1.93	3.28	
8	66.19	20.87	8.62	2.88	1.35	2.42	4.11	
9	66.73	21.86	7.07	2.93	1.36	3.09	5.25	
10	67.54	22.64	5.71	2.74	1.37	3.97	6.74	
11	62.38	17.50	14.99	2.82	1.27	1.17	2.00	$(2.8\text{CaO})\text{SiO}_2(2\text{CaO})\text{Al}_2\text{O}_3$
12	64.72	20.42	10.72	2.81	1.32	1.90	3.20	
13	65.50	21.27	8.85	2.82	1.33	2.40	4.08	
14	66.35	22.33	7.11	2.84	1.35	3.14	5.33	
15	67.31	22.76	5.59	2.77	1.37	4.07	6.92	
16								$(2.7\text{CaO})\text{SiO}_2(2\text{CaO})\text{Al}_2\text{O}_3$
17	64.35	20.61	10.82	2.86	1.31	1.91	3.24	
18	64.99	21.80	9.01	2.88	1.32	2.42	4.11	
19	65.76	22.70	7.32	2.89	1.34	3.10	5.26	
20	66.30	23.76	5.65	2.96	1.35	4.20	7.14	

The high-lime mixtures were burnt in a crucible furnace, lined with magnesite, fired with gasoline gas; the low-lime cements were burnt in an up-draft test kiln. All of the cements were cooled rapidly in the air as soon as vitrified. Owing to the iron content it was an easy matter to determine when vitrification had set in. No

difficulty was experienced in reaching the required temperatures, which ranged from 1270 to 1400° C. as measured by the Chatelier pyrometer. The burning temperature of the cements 1 to 5 was not determined, since the thermo couple could not be inserted in the crucible furnace without some risk to the wire. The clinker was carefully sorted, all underburnt as well as fused pieces being rejected. Owing to fear of contamination, the cements were ground in a mortar by hand and put through a 100 mesh sieve. The cement after screening, however, was found to be rather lacking in really fine dust, and hence did not show up as well in the tensile tests as cement ground in a ball-mill would.

The results of the tests are compiled in the following table:

Number.	Formula.	Ratio $\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	Appearance of clinker.	Tensile strength 1:3 pounds per sq. in. 28 days.	Boiling test.
1	$(3\text{CaO})\text{SiO}_2 (2\text{CaO})\text{Al}_2\text{O}_3 \dots\dots$	1.21	Yellowish, fusible.	49	Poor
2	"	1.90	Slightly yellow.	187	Poor
3	"	2.41	Good clinker.	180	Fair
4	"	3.08	Good clinker.	187	Fair
5	"	4.12	Good clinker.	203	Poor
6	$(2.9\text{CaO})\text{SiO}_2 (2\text{CaO})\text{Al}_2\text{O}_3 \dots\dots$	1.22	Brown slag.	.....	Poor
7	"	1.93	Fairly good.	193	Poor
8	"	2.42	Good.	168	Fair
9	"	3.09	Good.	232	Good
10	"	3.97	Good.	230	Good
11	$(2.8\text{CaO})\text{SiO}_2 (2\text{CaO})\text{Al}_2\text{O}_3 \dots\dots$	1.17	Slag like.	109	Poor
12	"	1.90	Fairly good.	228	Poor
13	"	2.40	Good.	305	Good
14	"	3.14	Good.	221	Good
15	"	3.97	Good.	188	Good
16					
17	$(2.7\text{CaO})\text{SiO}_2 (2\text{CaO})\text{Al}_2\text{O}_3 \dots\dots$	1.91	Fairly good.	102	Poor
18	"	2.42	Good.	67	Poor
19	"	3.10	Good.	122	Good
20	"	4.20	Good.	225	Good

The cements were allowed to cure for four weeks, but no gypsum was added. This, of course, made the high alumina cements quite quick setting. Five briquettes were made of each cement, 1 cement: 3 standard sand. Two boiling tests, 6 hours' boiling, were also made of each cement. Beginning with the formula $(2.6\text{CaO})\text{SiO}_2(2\text{CaO})\text{Al}_2\text{O}_3$, dusting was observed, and very low and unsatisfactory tests were obtained both as regards tensile strength and boiling tests. For this reason these have been omitted from the table.

In considering the results of the tests it must be remembered that cements with a silicious clay base harden much more slowly than aluminous cements, but attain after six months very high strengths, though showing up less promisingly in the short time tests. This was found to be true in a number of other experiments.

Conclusions.—1. From these results we can make the assertion that for dry ground mixtures the formula $(2.8\text{CaO})\text{SiO}_2, (2\text{CaO})\text{Al}_2\text{O}_3$ is the safest. This would correspond to the proportion, in parts by weight, of 1 part of silica to 2.61 parts of lime, or 1 part of silica to 4.66 parts of calcium carbonate. A cement made from a silicious clay and limestone would be decidedly unsafe with the theoretical tri-calcium silicate formula. From the results, however, no deductions can be drawn with reference to the theoretical silicates present in the cement. But the work seems to support the views of Vogt that we are dealing with a slag whose limits of composition are not as narrow as we might suppose. But at the same time there are quite definite limits, for with a formula of $(2.6\text{CaO})\text{SiO}_2, (2\text{CaO})\text{Al}_2\text{O}_3$, hydraulicity, as we know it in Portland cements, practically ceased and "dusting" began. This means that at this point hydraulic silicates can not crystallize out any longer. No coal ash was added to these cements at all, since they were not in contact with coal. The objection might be made that the formula would give too low a lime content owing to the introduction of silica and alumina in the ash from the coal when burnt in the rotary kiln. There is some justice in this objection, as the tendency of the ash will be to lower the lime content, and undoubtedly some reaction takes place.

Yet this naturally depends on the amount and composition of the ash and cannot be allowed for offhand, but must be regulated for each individual case. But the effect of the ash according to testimony collected from cement chemists is much less than is frequently supposed. That the cement composition is distorted by the presence of ash is, of course, obvious, and hence the usual analysis of a cement does not show its true composition. This can only be obtained by the ignition of the raw mixture without contact with coal. The fixing of the above practical formula does not take away the value of the Chatelier-Newberry formula as a limiting formula.

2. The ratios of silica to alumina given on several occasions seem to be correct, for the safest cements in the boiling test, though not the highest in the tensile test, are those with a silica-alumina ratio of from 3:1 to 4:1. Aluminous cements are to be condemned.

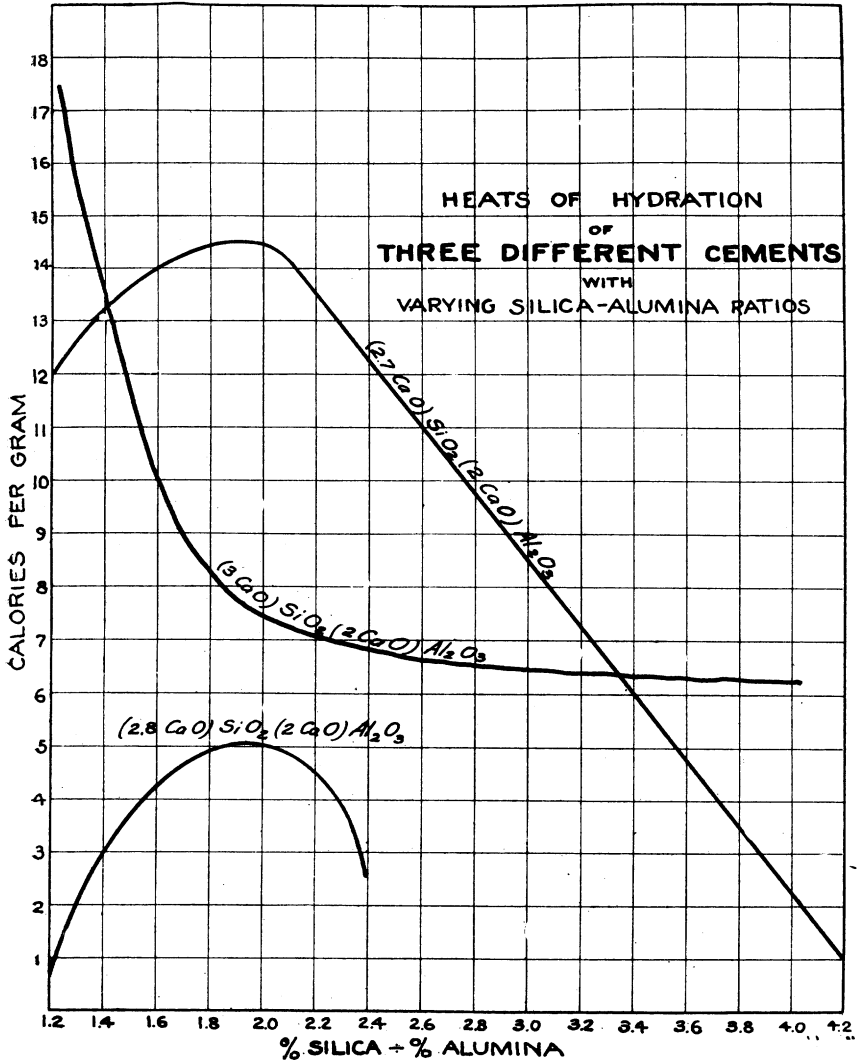


Fig. 28. Curves showing heats of hydration of three cements of varying silica-alumina ratios.

Some of these cements were tested in the calorimeter by Mr. Edward Thomas, a former student of the writer. Ten grams of the cements were taken and 100 cc. of distilled water. The results of these determinations are plotted in the accompanying curve, and show quite clearly that the silicious cements possess lower heats of hydration in spite

of a higher lime content than the more aluminous clay bases. Unfortunately these tests are not quite as complete as it was desired to have them. It was also intended to carry on these tests by adding to the cements a little more water than they require for complete hydration, say 25 per cent., placing the cement and water into a metal capsule and immersing the latter in water. The rise in temperature would then give the hydration value under conditions approaching the practical reaction. Time, however, did not permit of carrying out these tests. For purposes of comparison the hydration values of a number of standard Portland cements are given, using 10 grams of the sample and 100 cc. of water.

	Calories per Gram.
No. 1.....	3.43
2.....	6.41
3.....	1.35
4.....	3.98
5.....	1.04

In order to supplement the results of the preceding series in regard to the best practical formula for dry ground mixtures of clay and limestone, the following cements were prepared, using as a basis a silicious clay found on the campus of the Ohio State University, a drift deposit of the following composition:

	Per cents.
Silica.....	68.82
Alumina and iron oxide	19.20
Calcium oxide.....	2.69
Magnesium oxide.....	2.46

The limestone was a Carboniferous stone from near Wellston, Ohio, of the composition:

	Per cents.
Calcium carbonate.....	91.80
Silica.....	3.52
Alumina and iron oxide.....	3.51

These materials were mixed and ground together intimately in the dry condition in an iron ball-mill, containing flint pebbles. The time of grinding was four hours, and practically no residue was left on the 100 mesh sieve.

The clinker, after burning to complete vitrification, was ground in the ball-mill to a powder, leaving no residue on the 100 mesh sieve. No gypsum was added to the cement. The results of the test were as follows:

Formula employed.	Tensile strength 1:3, 28 days. Pounds per sq. in.	Boiling test.
$(2.9\text{CaO})\text{SiO}_2 (2\text{CaO})\text{Al}_2\text{O}_3$	290	Good.
$(2.8\text{CaO})\text{SiO}_2 (2\text{CaO})\text{Al}_2\text{O}_3$	360	Good.
$(2.7\text{CaO})\text{SiO}_2 (2\text{CaO})\text{Al}_2\text{O}_3$	225	Good, off glass

Five briquettes were used in each test. This work was repeated with practically the same results by two students.

Examples of Cement Batch Calculation.—To illustrate the method of calculating the composition of a cement mixture, the following example is worked out:

Given the clay mentioned above:

68.82 % silica,
19.20 % alumina and iron,
2.69 % calcium oxide,
2.46 % magnesium oxide.

and the limestone:

91.80 % calcium carbonate,
3.52 % silica,
3.51 % alumina and iron.

The formula $(2.8\text{CaO})\text{SiO}_2, (2\text{CaO})\text{Al}_2\text{O}_3$ requires for every part by weight of silica 4.66 parts of calcium carbonate, and for every part of alumina two parts of the carbonate. The clay requires, therefore,

$$\begin{aligned} 68.82 \times 4.66 &= 320.7 \text{ parts,} \\ 19.20 \times 2.00 &= 38.4 \text{ parts.} \end{aligned}$$

359.1 parts calcium carbonate.

But as the clay contains 2.69 per cent. calcium oxide, we must deduct this amount, as the carbonate, and we obtain: $359.1 - (2.69 \times (100 \div 56)) = 354.3$ parts of calcium carbonate required.

On the other hand, the limestone contains silica and alumina, which take up some of the calcium present, so that the amount available is $91.8 - (3.52 \times 4.66 + 3.5 \times 2) = 68.4\%$ of calcium carbonate. The amount of limestone to be used for one part of the clay is therefore $354.3 \div 68.4 = 5.179$ parts, or 100 parts of clay require 518 parts of limestone. In this calculation the ferric oxide has been taken together with the alumina, as the difference due to allowing for the iron is negligible. In practical work the calculation is simplified by the use of logarithms, curves, or tables analogous to the slag tables used in blast furnace work.

Meyer's Method.—There are also other methods of calculating cement mixtures. Meyer thus advises the use of the formula:

$$x((3\text{CaO})\text{SiO}_2) + y((n\text{CaO})\text{SiO}_2\text{R}_2\text{O}_3),$$

in which the value of $n=3$ to 4. This is highly commended by some European chemists. This formula has also been stated as follows: $a\text{MO} + b\text{Al}_2\text{O}_3 + \text{rSiO}_2$, in which MO is the sum of the equivalents of lime, magnesia, iron oxide and alkalis, a is equal to the minimum value, 3, and the maximum value $3+b$, b of course is the equivalent of alumina. Illustrating the application of this formula by an example* and assuming that we are dealing with two materials of the following composition:

	Limestone.	Marl clay.
Silica.....	1.2	42.0
Alumina.....	0.5	10.2
Calcium oxide.	50.4	22.4
Magnesia.....	1.6	....
Ferric oxide.....	....	4.0
Loss on ignition.....	46.3	21.4

we obtain the equivalents by dividing each percentage by its molecular weight.

If now x is the number of parts by weight for one part of clay, the mixture, raw or burnt, contains:

Lime plus fluxes ($=\text{MO}$)	$0.94x + 0.95$
Alumina	$0.005x + 0.10$
Silica	$0.02x + 0.70$

For a cement of the lower lime limit ($\text{CaO}=3\text{SiO}_2$) we have

$$0.94x + 0.45 = 3(0.02x + 0.70).$$

For the upper lime limit ($\text{CaO}=\text{Al}_2\text{O}_3 + 3\text{SiO}_2$) we obtain:

$$0.94x + 0.45 = 0.005x + 0.10 + 0.02x + 0.70.$$

For a medium limit we have:

$$0.94x + 0.45 = \frac{1}{2}(0.005x + 0.10) + 3(0.02x + 0.70).$$

Solving for x , we find it equal to 1.94. Hence for one part of clay there must be used 1.94 parts of limestone. The cement contains, then:

$$2.27\text{MO} + 0.1097\text{Al}_2\text{O}_3 + 0.7388\text{SiO}_2.$$

Letting $\text{SiO}_2=1$, the formula will be:

$$3.075\text{MO} + 0.15\text{Al}_2\text{O}_3 + 1\text{SiO}_2,$$

which is the desired composition.

*Taken from the *Tonindustrie Zeitung*.

Hydraulic Modulus Method.—A method of calculation generally used in Europe depends on the so-called hydraulic modulus, which may be stated as follows:

$$\frac{\text{Per cent. calcium oxide}}{\text{Per cent. silica} + \text{per cent. alumina} + \text{per cent. ferric oxide}} = 2.$$

That is, the content of calcium oxide should be twice as great as the sum of the percentages of silica, alumina and ferric oxide. The permissible variations range from 1.8 to 2.2. This formula is much cruder and more inaccurate than the Chatelier formula, as it does not discriminate between the three constituents in the denominator, for the requirements of the formula would be met just as well by a highly aluminous clay or a silicious iron ore. However, it gives a readily available check on the other method, provided a suitable clay is being used. The sum of the three constituents, silica, alumina and iron is briefly called "silicate"= s . The lime contents we let= c and the modulus n . If a clay contains s parts of silicate, and c parts calcium oxide, the latter requires $c \div n$ parts of silicate, which is to be subtracted from the s parts of silicate. The remaining parts of silicate, $s - (c \div n)$, require n times as much lime, or $n[s - (c \div n)]$ parts of calcium oxide.

If the limestone contains s_1 parts of silicate and c_1 parts of lime, the former requires again $n.s_1$ parts of the latter, so that there are available only $c_1 - n.s_1$ parts of calcium oxide. We know, however, that the clay requires $n[s - (c \div n)]$ parts of lime, and hence as many parts of limestone must be taken as will furnish the required number of parts of caustic lime or the ratio must be:

$$n(s - \frac{c}{n}) \div (c_1 - n.s_1)$$

This gives the formula:

$$\frac{\text{Limestone}}{\text{Clay}} = \frac{n(s - \frac{c}{n})}{c_1 - n.s_1} = \frac{n.s - c}{c_1 - n.s_1}$$

To illustrate:* A clay contains 63 per cent. of silicate and 25 per cent. of calcium carbonate= 14 parts of calcium oxide. The limestone contains 10 per cent silicate and 87.5 per cent of carbonate= 49 parts of caustic lime. If the modulus is to be 2, the proportion of limestone and clay to be used is:

$$\frac{\text{Limestone}}{\text{Clay}} = \frac{2 \times (63 - 14)}{49 - (2 \times 10)} = \frac{112}{29} = \frac{3.86}{1}$$

This method of calculation is not recommended for general use.

*Schoch, *Moertelmateriatien*, p. 90.

A Simple Algebraic Method.—After once the best proportion of a mixture has been established, the daily mixture can be calculated from the raw materials available by a simple calculation depending on the lime content of the two materials.

Let x =weight of limestone in charge,
 y =weight of clay in charge,
 a =per cent. of calcium oxide in the limestone,
 b =per cent. of calcium oxide in the clay,
 c =per cent. of calcium oxide in the mixture,
 then $c = \frac{ax+by}{x+y}$ or $x(a-c) = y(c-b)$ or $\frac{x}{y} = \frac{c-b}{a-c}$

Experimental Apparatus for Cement Burning.—Preliminary burning tests are made by weighing out the ingredients, grinding them to a powder in a ball-mill, moistening the dust and making into small balls or cubes and burning them in a test kiln. The writer employed for grinding his mixture the iron ball-mill already mentioned, which has the shape of a flattened sphere, 24 inches in diameter and $7\frac{7}{8}$ inches wide at the center, making 27 revolutions per minute. The mill is made of chilled iron, and provided with a cap whose surface, as well as the surface of the mill opening, are ground, forming a tight joint. With 126 pounds of flint pebbles, 30 to 40 pounds of mixture can be ground sufficiently fine in from three to five hours. This mill is shown in Fig 29.

For the burning the writer employed a crucible furnace, lined with a mixture of 90 parts of burnt magnesite and 10 parts of Portland cement, with an inside diameter of 4 inches and a height of 6 inches, fired with gasoline gas, and using air under a pressure of about 18 pounds to the square inch, furnished by a Westinghouse locomotive air pump. This was quite satisfactory for smaller quantities; after once heated, a highly calcareous cement could be burnt in 20 minutes. The furnace space was simply filled with the balls of the raw mixture which were, of course, perfectly dry.

For larger quantities of cement requiring a high temperature a furnace shown by figure 30 on page 245 was used which consisted essentially of a straight shaft of fire-brick, with 4 inch walls, and divided into three distinct divisions. Into a space 4 inches high at the bottom, air was forced under a pressure of about 12 ounces, from a blower through a 2 inch pipe. This space was divided from the next division by means of a cast iron plate provided with concentric rows of holes. Above this plate, about 5 inches away from it, an iron pan was

supported by two bricks, petroleum being fed into this pan by means of a $\frac{1}{4}$ inch pipe. The oil was forced in by gravity from a can some distance away from the furnace. On this pan evaporation of the petroleum took place after the furnace was in operation. Several inches above the pan, the whole cross-section of the shaft was filled with broken firebrick so as to bring about the mixture of the petroleum vapors with the air blown in.

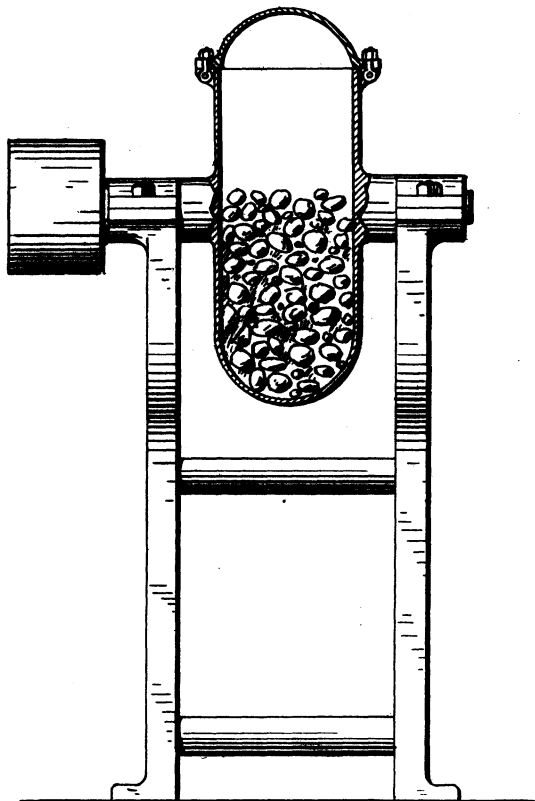


Fig. 29. Ball mill for grinding samples of cement.

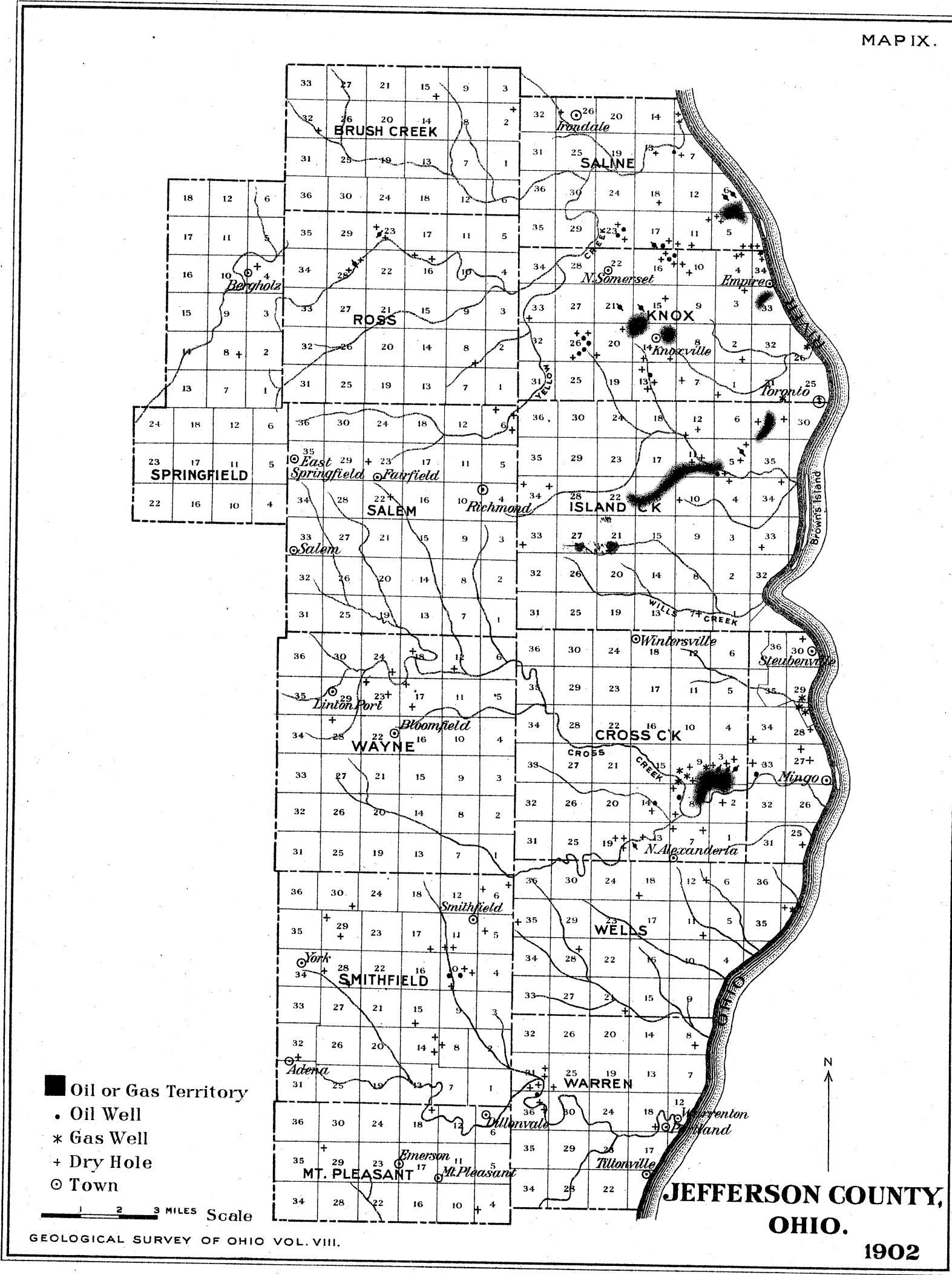
Above this compartment the third compartment was formed by a grating of bricks. At first magnesite bricks were used, later porous bricks from a mixture of 80 per cent. magnesite and 20 per cent. of Portland cement were employed. On this grating the balls of cement mixture were heaped up to the top of the compartment which had a height of 8 inches. The cover consisted of a perforated clay tile upon which were piled broken bricks, so as to keep the heat from rushing out too rapidly. The clinker compartment was accessible from the outside by means of a door, which was closed by a firebrick plug which could be removed and the clinkers withdrawn and examined.

This furnace can be readily used for high temperatures. The time required to make a burn, including the heating up, is about two hours. A hole at the level of the iron plate permits of introducing the small amount of paper and wood necessary to start the flame, by heating the pan. By removing the pan, bricks and broken pieces, this furnace was also used for burning with coke, which, though not as convenient and rapid, was accomplished successfully. An opening, closed by a plug, beneath the plate, permitted of withdrawing the fine dust and ashes which filtered through, while the coal clinkers were removed through the hole at the level of the plate. The coke was charged through a door just beneath the grating supporting the cement clinker. In firing with coke, it was found best to use a good grade of firebrick, since the magnesite bricks, even those made of the magnesite-cement mixture, proved to be too brittle and friable to withstand the sudden cooling on opening the door. The layer of coke must be kept as thick as possible.

An updraft kiln of the Ohio State University Ceramic Department was also used successfully for burning ordinary cement mixtures, a temperature of cone 12, 1370° C. being attained without difficulty. For the usual testing work where contamination with the ash of the fuel is not objectionable, the ordinary type of the shaft furnace, similar to an assay furnace, without a muffle, the draft being furnished by a stack, is quite sufficient. It is simply a rectangular shaft, with a grate and ash-pit bottom. Wood is placed on the grate and on top of that a heavy layer of coke. Cubes of cement mixture are charged on top of the fuel in a thin layer, followed by more coke. In this manner alternate layers of coke and cement are arranged.

Professor Campbell, of the University of Michigan, used, very successfully, a small rotary kiln, consisting of an inclined iron pipe, 8 inches in diameter and 32 inches long, which was lined with four sections of a hard burnt magnesite pipe, whose inside diameter is 3 inches. The furnace is rotated by means of a $\frac{1}{2}$ horsepower motor and makes one revolution in 1 minute and 25 seconds. It is fired by means of a Hoskins gasoline burner and air is supplied at about 50 pounds to the square inch. On measuring the temperature by means of the Chatelier pyrometer, it was found to be the highest about 6 inches from the lower end, it being 1500° C. After the kiln is heated up, the mixture is charged and with an inclination of 6° takes 25 to 35 minutes to pass through the kiln. During the first hour 1,500 to 1,700 grams are fed; after the first hour, 1,000 to 1,200 grams per hour; this means 600 to 700 grams of clinkered material per hour.

For research work, electrical furnaces are extremely useful, allowing of quick firings and absolute control of the temperature. Platinum foil



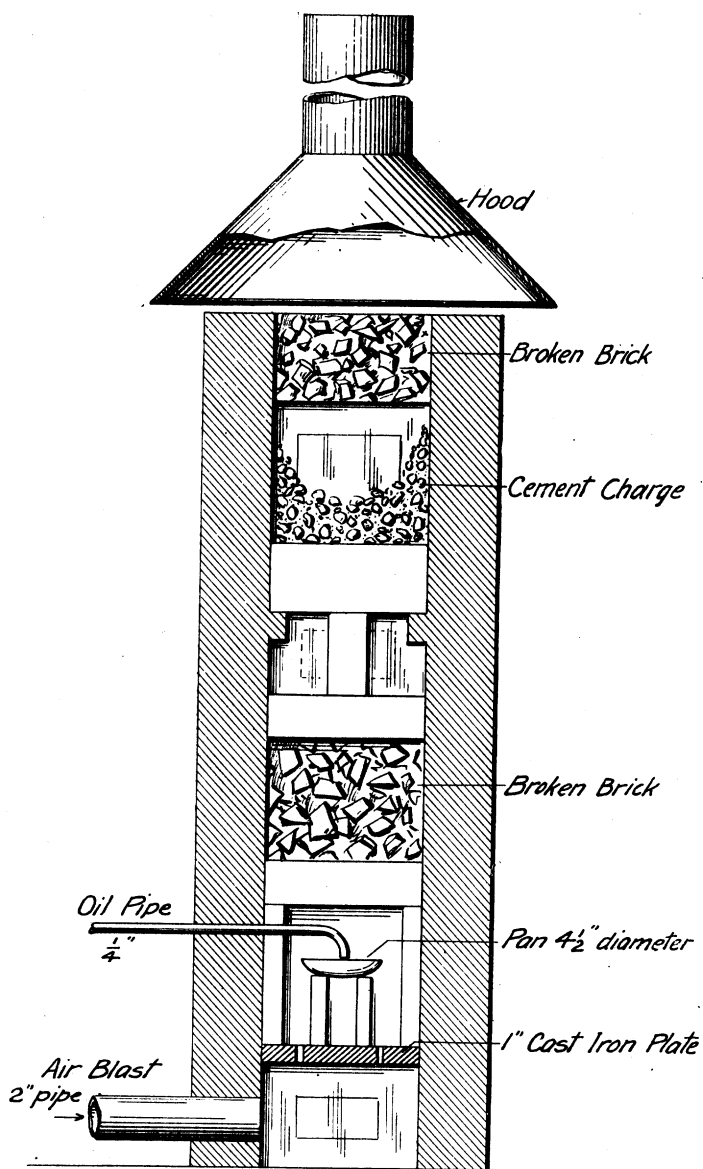


Fig. 30. Kiln for burning sample batches of cement.

resistance furnaces, however, are quite troublesome above a temperature of 1200°C ., owing to the conduction of the heating cylinder and consequent danger of short circuits. The Hempel carbon resistance furnace would prove very suitable, and of late a furnace has been offered on the market which certainly seems to be an exceedingly simple apparatus, consisting mainly of a refractory cylinder of fire-clay or basic material surrounded by a special resisting material, called "Kryptol." It is claimed that the "Kryptol" furnace produces a temperature of 2000°C . quite readily, depending on the refractoriness of the cylinder. It consumes from 3 to 5 kilowatts per hour, according to the temperature and size. The temperature measurements must be made with an optical pyrometer, but can be carried out even with an ordinary photometer.

Corrections of the Cement Composition.—In the following table a few general corrections are given which may be followed if the clinker produced, experimentally or on a large scale, shows certain defects:

Defect of cement.	Correction.
Too difficult to vitrify.	Decrease lime content, or add more ferric oxide in the shape of an ore, or add fluorspar to raw cement.
Vitrified too rapidly.	Increase silica content of clay base and lime content.
Yellowish clinker.	Increase silica content in clay base.
Sets too rapidly.	Increase silica content in clay base, or add fluorspar to raw mix, or add ferric oxide to raw mix, or add ground gypsum to burnt cement.
Sets too slowly.	Reduce silica content.
Not constant in volume (does not stand boiling test.)	Store longer. Decrease lime content or increase content of ferric oxide, or increase silica content in clay base; grind raw mixture finer; reduce sulphur content.
Tendency to dust.	Increase lime content; quench clinker in water or cool rapidly in air; add ferric oxide to raw mix.

Defect of cement.	Correction.
Too low in initial tensile strength.	Increase lime content and grind raw mix finer, or increase alumina somewhat; grind clinker finer.
Too low in final tensile strength or showing a deterioration in strength.	Increase silica in clay base.

CHAPTER VII.

WINNING AND PREPARATION OF THE RAW MATERIALS.

According to the nature of the various raw materials the method of winning them must differ. It is impossible to consider all the details of the quarrying and digging, but we must let it suffice to make a brief outline of the processes practicable.

THE CLAYS.

As to the clays, we have, according to their nature, the following methods of winning them:

1. Hand digging.
2. Quarrying.
3. Use of plow and scraper.
4. Steam shovel.
5. Dredging.
6. Mining.

Hand Digging.—Hand digging is practiced where the daily output is small and the clay is soft enough to be picked and shoveled without too much effort. The cost of digging clay is at least 35 cents per cubic yard.

Quarrying.—Quarrying is employed with shales. The material is worked in benches and is blasted with powder, dynamite being as a rule too quick in its action. By means of proper "undercutting" large quantities of material can be handled. The cost is probably around 25 cents per cubic yard.

Plow and Scraper.—The plow and scraper are very suitable in larger areas of soft clay, comparatively level. The common scrapers should not be used for distances over 200 feet. For greater distances a platform may be used, to the top of which the scraper is drawn and dumped through a grating into a car, cart or wagon. The wheel scraper may be used for longer distances, not exceeding 500 feet. The cost per cubic yard is about 20 cents.

Steam Shovel.—The steam shovel, either continuous with an endless chain carrying buckets with a cutting edge or intermittent like the usual

steam shovel. These are made in various sizes, handling from 400 to 5,000 cubic yards per ten hours. For cement works the smaller shovels handling from 400 to 800 cubic yards in ten hours will be of sufficient capacity. If the steam shovel is to be used for shale the bucket must be provided with sharp steel teeth for first cutting the shale, after which the material is shoveled into the car. The bucket capacity should be $\frac{3}{4}$ or 1 cubic yard. The cost of winning material by this method is probably from 5 to 12 cents per cubic yard.

Dredging.—Dredging is practiced in obtaining clay from river or lake bottoms or in very wet, low country, as in the lake region of Michigan and Indiana. It would seem that for this work a continuous bucket dredge would be preferable to the ordinary dipper dredge, as it would enable the manufacturers to dredge deeper. The writer has, however, seen a barge dipper dredge working to a depth of thirty feet without any difficulty. The cost of dredging in this manner is not great, probably not over 4 cents per cubic yard of 58 per cent. moisture, which is equivalent roughly to $1\frac{3}{4}$ barrels of cement.

Mining.—Mining is practiced only where absolutely necessary, and is not carried on at any cement works to the knowledge of the writer, though there is no reason why it should not be undertaken if necessary. In mining, the main requisite is a strong thick stratum overhead, preferably sandstone. A clay roof is dangerous and causes expensive mining. The cost of mining is always heavy, from 50 cents to 75 cents per ton, depending on the thickness of the vein, nature of roof and floor, hardness of the rock, mechanical aids available, etc. The cost of the dead work, track, posts and timbers is about 25 cents per ton, varying with the locality, etc.

WINNING OF LIME MATERIALS.

The methods of winning the calcareous materials according to their character may be classified as:

1. Quarrying.
2. Dredging,
3. Steam shovel work.
4. Mining.

Quarrying.—Quarrying is applied, of course, only in working limestones or cement rock and needs no detailed description. Power drills should be employed, worked either by compressed air, steam or electricity. It is rather difficult to give general figures of the cost of quarrying, but probably 20 cents per ton is not far from the truth.

Dredging.—Dredging is practiced in winning the calcareous marls of Michigan, Indiana and Ohio. The amount of high calcium marl required for one barrel of cement varies from 8 to 12 cubic feet, with

a moisture content of from 50 to 70 per cent.; 10 cubic feet may be safely taken as the average. In prospecting a marl deposit, it is extremely important to make numerous borings in order to calculate the available marl. Owing to the extreme variations which this material is liable to show, it is quite deceptive, and often the variation is far greater than appears on superficial examination. Neglect to look this over carefully has necessitated the closing down of more than one marl plant. In Michigan the marl area controlled by a single cement plant varies from 260 to 2,000 acres.

Steam Shovel.—The steam shovel cannot be employed, as a rule, for winning limestone, though the writer has seen one most powerful machine at work at the Edison Portland Cement Company. In this case a cement rock is being worked by blasting, the machine taking up the loosened material. Calcareous material, of a soft nature, like dry marls, chalk or soft limestones can be worked very economically by means of the steam shovel, and the cost will not be much more than 5 cents per cubic yard.

Mining.—What has been said in regard to clays applies also here, excepting that limestones would be less difficult to mine, owing, as a rule, to the better roof available and the more stable character of the pillars. But the cost, though not as great as for clay, would not be very much less, probably not less than 40 cents per ton.

HAULAGE OF RAW MATERIALS TO WORKS.

There are available four means of conveying the raw materials to the works, which are:

1. Tramways..

{	Cable
	Electric locomotive
	Steam locomotive.
2. Aerial cableways.
3. Transportation by water.
4. Pumping.

The method of haulage to be adopted depends on the distance to be covered, the quantity to be conveyed and the topographical conditions.

Tramways.—Cable tramways are suited only for short distances and are especially useful in dealing with heavy grades. For larger capacities the rope should be endless so as to keep cars going steadily in one direction. Where the grade is sufficient in the right direction, a gravity system can be installed, the loaded cars pulling up the empty ones. It is unnecessary to go into details of construction of such plants, since these have been thoroughly worked out for mining work and such a discussion would be beyond the scope of this report. The distance should not exceed about 1,500 feet. Electric and steam propelled locomotives are adapted

specially to longer haulages, distances up to three miles not being infrequent in this kind of work. For short distances, animal power can be employed in plants with a capacity up to 500 barrels per day.

Aerial Tramways.—Aerial tramways are only advisable for locations with an extremely rugged topography, since they are expensive to construct and to maintain. They are useful, however, where rivers or valleys are to be crossed. We must distinguish between the single moving rope cableway, which supports and moves the load at the same time, and the double cableway, which has two or more supporting ropes and an endless pulling rope. The former can carry single loads up to 200 pounds, has a capacity up to 200 tons per day, and may be built as long as $1\frac{1}{2}$ to 2 miles. The second class of cableways is used most largely. These cableways are provided at the terminals with devices for loading and discharging, also with the driving gear for moving the traction rope and brakes. The intermediate supports are of wood or steel. The cars are simply buckets provided with wheels which run on the heavy supporting rope, and a friction grip for attaching to the pulling rope. These buckets may hold a load up to 1,400 pounds, and the pulling rope may have a speed of from 150 to 350 feet per minute. The economical limit of length is probably two miles. The cost of construction is from \$5,000 per mile up. As to the power required, this differs, of course, quite widely, and depends on many factors.

One formula given requires for n , the horsepower necessary,

$$n = \frac{qu}{270} \left(\frac{1}{100} (2 + 0.005(100 - qu)) + h \right) + N_0.$$

Where l is the length of the cableway in meters,

qu = the quantity to be hauled in tons per hour,

h = the difference in level of the terminals, plus for upgrade, and minus for downgrade.

N_0 = a constant, varying from 0.5 to 5, allowing for friction. The capacity of double cableways is from 200 to 1,000 tons per ten hours.

Transportation by Water.—Transportation by water is employed especially where the lime material is dredged or where located on a suitable waterway. This affords a very cheap method of transporting large quantities of material.

Pumping.—Pumping is frequently practiced in dredge work where the dredged material is mixed up with more water and made up into a slurry containing about 60 per cent. of water by means of a pug-mill, the material having been run through a stone and root separator, which is simply a perforated revolving cylinder. At the works of the Peninsular Portland Cement Company, the slurry is pumped from the dredge to the works, the pipe having a flexible connection, and being supported

by stakes driven into the lake bottom. This is applicable only where deep dredging is practiced, the dredge being moved but slowly. At other marl plants the dredged marl is taken by means of scows to the mill and pumped from the scow into large reservoirs. The slurry is forced along the mains by compressed air; this being far superior to the work of plunger pumps. The writer has seen in Germany clays handled by stirring up with water in agitators, screening, and then pumping for distances as great as two miles. In this way, coarse sand, roots, etc., are at the same time removed completely.

Wherever solid material is being hauled, it should be dumped into large bins with steep iron-sheeted bottoms from which the rock can be allowed to drop into the chutes leading to the crushers. One man can thus feed a large quantity of material with but slight effort. The gates for controlling the flow of heavy, coarse material from bins are heavy plank affairs, with a few heavy iron teeth which will stop the sliding of the material with the greatest ease.

GRINDING OF RAW MATERIALS.

In the United States we must distinguish clearly three modes of preparing the raw mixtures, depending on the three combinations of raw materials available:

First, the cement rock and limestone combination employed in the Lehigh Valley, Pennsylvania.

Second, the limestone and clay mixtures wherever suitable limestone and clay is found.

Third, the marl and clay mixtures used in Michigan, Indiana and northern Ohio.

It becomes at once evident that the first and second, working with dry and hard material, must employ practically the same class of preparing machinery, while the materials of the third combination naturally call for machinery adapted to working them in the wet state, though, of course, this becomes optional to some extent, since the slurry may be dried at once, and then worked dry. But this is not the regular procedure, especially in working with rotary kilns.

Preliminary Dryers.—Frequently the clay or the limestone or both must be dried before they can be taken through the grinding machines. This is accomplished by means of rotary dryers which consist essentially of a revolving brick-lined iron tube, 40 feet long and 54 inches in diameter, revolving on two sets of carrying rollers and driven by a train of gearing. Heavy steel tires made in halves are attached to cast iron riding rings riveted to the shell. The heat is produced by an ordinary furnace fired with coal like a boiler furnace, the heated combustion gases and air passing through the tube and out into the stack. The materials to be

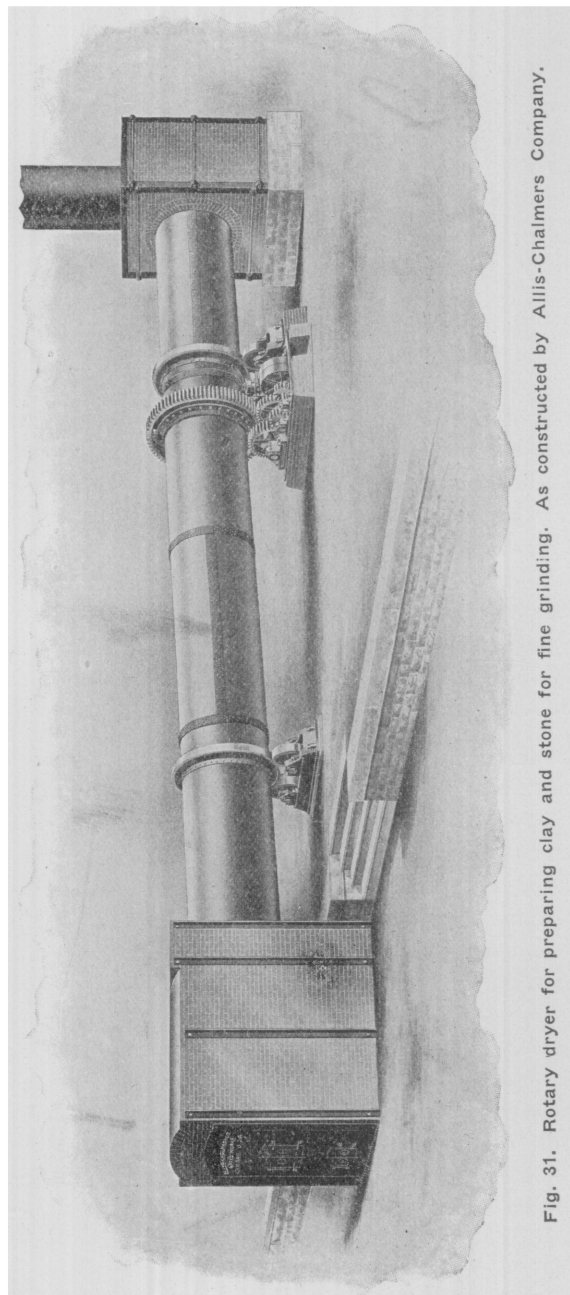


Fig. 31. Rotary dryer for preparing clay and stone for fine grinding. As constructed by Allis-Chalmers Company.

dried are charged at the stack end and discharged, hot, at the furnace end. The capacity of such a machine is from 5 to 10 tons per hour, depending on the condition of the material and the amount of moisture contained by it. It requires from 4 to 6 horsepower for operation. Owing to the fact that this machine discharges the dried material when still hot and the gases leave the machine far from saturation it is not the most economical type of dryer. Other systems, like the Cummert dryer and others, make better use of the heat, but at the same time are more troublesome to operate. The dryer shown by the accompanying illustration is a simple and, mechanically, an efficient machine, though not the most economical type. It is, however, to be preferred to any complicated system in which the heat efficiency is counteracted by mechanical difficulties.

ROUGH CRUSHING MACHINES.

The dry materials require three kinds of preparing machinery:

1. Rough crushing machines,
2. Intermediate grinding machines,
3. Fine grinding machines.

These three operations must be clearly kept in mind, as they cannot be carried on successfully at one and the same time.

Of the rough grinding machines two types are employed, known generally as the jaw and spindle crusher respectively. In addition another type is employed, as far as the writer knows, only in one instance, namely the roll crusher.

Jaw Crusher.—Under the type of jaw crusher we understand a number of machines, which though they differ in regard to the movement of the jaw, or in the number of jaws employed, yet employ the one general principle. Thus, we know the Dodge breaker, the Buchanan, the Duplex breaker, the Forester, the Kron, the Sturtevant and others. The Blake crusher is considered typical. Its action is simply the opening and closing of steel-faced iron jaws, moved by toggles which are set in motion by a vertical eccentric motion. A seven inch by ten inch Blake crusher has a movement at the mouth of 0.78 inch, at the throat of 0.25 inch, and makes 275 revolutions per minute. As a piece of rock is seized by the jaw, it is gradually crushed to a smaller and smaller size and worked down towards the throat, the width of which governs the size to which the rock is broken. The fixed and the swing jaw plates are often made of the hardest steel obtainable, chrome or manganese steel; if these are not used, chilled iron is found to be the cheapest. In work of this sort the most essential requirement is, of course, that the machine be amply strong enough for the strains it has to withstand, even if this should be accomplished at the cost of some of the capacity. They should be able to take the largest lump and reduce it without the necessity of breaking up with a sledge. The cost of crushing with a jaw crusher has

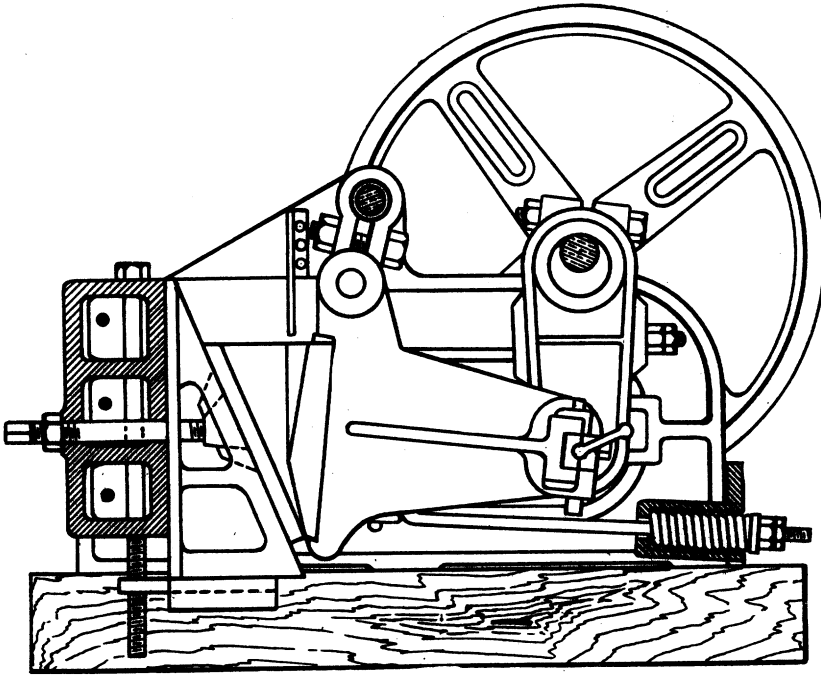


Fig. 32. Jaw crusher of the Blake type.

been assembled by Prof. Richards, in his work on Ore Dressing as follows:

Size of mouth in inches.....	4 x 10	7 x 10	9 x 15	10 x 20	13 x 30
Tons crushed in 24 hours	84	120	192	300	540
Horsepower.....	5	8	12	20	30
Cost of breaker.....	\$275	\$500	\$750	\$1,050	\$2,250
Cost in cents per ton for oil.....	0.021	0.021	0.021	0.021	0.021
Cost in cents per ton for interest and depreciation.....	0.106	0.135	0.127	0.114	0.135
Cost in cents per ton for labor....	4.762	3.333	2.083	1.333	0.741
Cost in cents per ton for power...	0.773	0.865	0.811	0.865	0.721
Cost in cents per ton for wear....	0.815	0.815	0.815	0.815	0.815
Cost in cents per ton for repairs. .	0.462	0.462	0.462	0.462	0.462
Total cost in cents per ton.....	6.939	5.631	4.319	3.61	2.895

These estimates, however, are based on hard materials and hence are rather higher than the cost of crushing limestone.

Spindle Crushers.—These machines differ from the jaw crushers inasmuch as the crushing is continuous, being done by a gyrating vertical spindle, whose upper part has the shape of a truncated cone and which is set in motion by means of a bevel gear. The cone rotates within a conical space representing an inverted cone. As long as the machine is empty the spindle rotates, though it could assume a gyratory motion. But as soon as rock is fed between the crushing surfaces the spindle follows an eccentric just beneath the bevel wheel. This causes the head to approach and recede from the concave grinding surface of the shell surrounding the cone, the movement at the bottom of the truncated cone being greater than at the top. The result is a crushing action by pressure which has a greater movement upon the smaller lumps than upon the larger. The fulcrum of the machine is located at the bottom of the upper journal of the spindle. A lump thrown into the machine is broken, drops, catches again, is again broken, and thus continues on its way down. The fineness of the output can, of course, be regulated by regulating the width of the throat.

Professor Richards gives the following table showing the cost of crushing by spindle breakers:

Size of mouth, in inches.....	4 x 30	6 x 42	8 x 54	11 x 72	18 x 126
Tons crushed in 24 hours.....	72	216	540	1,080	3,000
Horsepower.....	3	9	22	45	125
Cost of breaker.....	\$375	\$760	\$1,800	\$3,300	\$7,000
Cost in cents per ton for oil.....	0.021	0.021	0.021	0.021	0.021
Cost in cents per ton for interest and depreciation.....	0.169	0.114	0.108	0.099	0.076
Cost in cents per ton for power....	0.541	0.541	0.541	0.541	0.541
Cost in cents per ton for labor....	5.556	1.852	0.741	0.370	0.133
Cost in cents per ton for wear....	0.971	0.971	0.971	0.971	0.971
Cost in cents per ton for repairs..	0.308	0.308	0.308	0.08	0.308
Total cost in cents per ton.....	7.566	3.807	2.678	2.310	2.050

Comparative tests of the Gates Iron Works have shown the following results in crushing a hard granite with a crushing strength of 30,000 pounds per square inch, in lumps as large as the machine would take.

The Blake crusher represents the jaw crusher type, the Gates the spindle crusher type.

Details of Contesting Machines

Kind of machine.	Mouth size, inches.	Width of throat inches.	Movement at throat, inches.	Revolutions of driving pulley per minute.	Kind of shoe.	Kind of die.	Material used, lbs.	Time required, minutes.	Capacity per hr. Pounds.	Net power used, H. P.	Relative work used in crushing.
Gates, No. 0	4 x 33	0.9375 to 1	0.3125	500	Corrugated	Smooth	1,000	3.33	18,000	5.2	100
Blake	4 x 10	0.8125 to 0.875	0.3125	250	Corrugated	Corrugated	1,000	5.33	11,200	6.1	187
Gates, No. 3	7 x 48	1.5 to 1	0.5	450	Corrugated	Smooth	2,000	2.66	45,000	21.7	100
Blake	7 x 10	1.25 to 0.75	0.5	250	Corrugated	Corrugated	2,000	6.66	18,000	12.45	144

Sizing Tests of Products of Spindle and Jaw Crushers.

	On 2.5 inch.	Thro 2.5 and on 2.0.	Thro 2.0 and on 1.5.	Thro 1.5 and on 1.0.	Thro 1.0 and on 0.75.	Thro 0.75 and on 0.5.	Thro 0.5 and on 0.25.	Thro 0.25 and on 0.125.	Total.
Gates 4 x 33.....	3.0	5.3	24.2	35.0	9.9	8.4	6.3	3.2	4.7
Blake 4 x 10.....	7.0	10.0	23.0	23.2	6.4	9.9	8.7	4.5	7.3
Gates 7 x 48.....	5.0	17.5	27.0	20.8	6.7	7.3	9.0	2.7	4.0
Blake 7 x 10.....	6.5	23.0	21.1	17.8	4.8	7.9	8.2	4.1	6.6

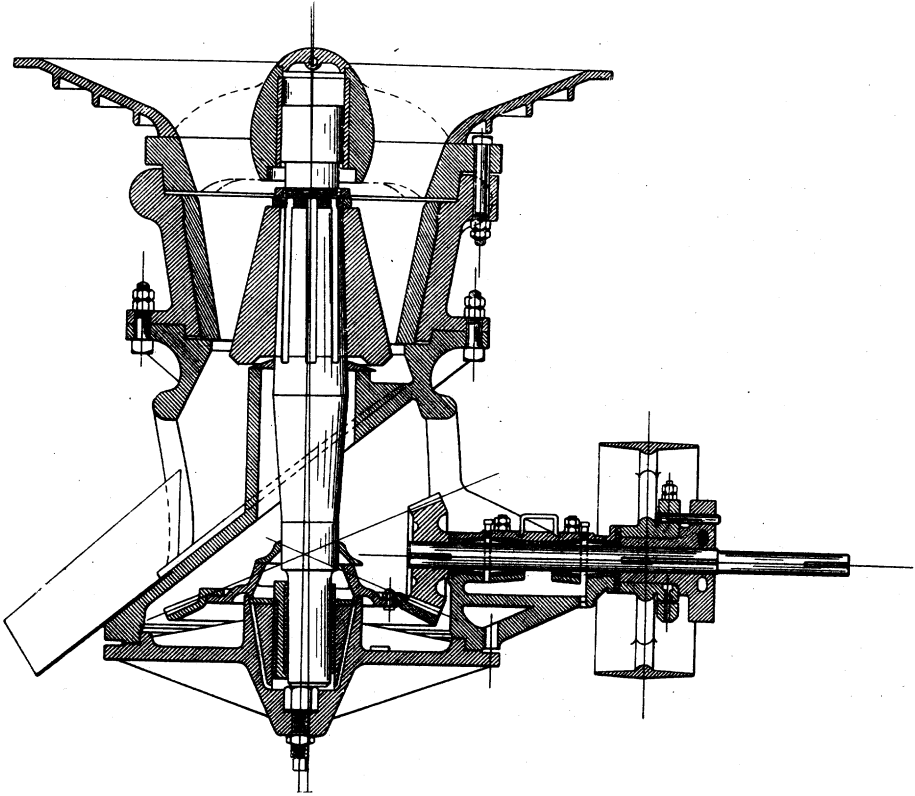


Fig. 33. Spindle crusher, Gates type.

In these tests the Blake crusher was handicapped by its small size and the smaller width of throat. The general tendency seems to be in favor of the Blake crusher for small and in favor of the Gates for greater capacities. The continuous action also is in favor of the Gates crusher.

In cement practice a rock crusher with an average capacity of 25 tons per hour requires under conditions of maximum load 33 horsepower and an average of 20 horsepower.

Rolls.—These are two iron cylinders revolving on shafts in the direction indicated by the arrows in the accompanying diagram acting upon the lump of material *c* on the principle of a toggle joint. The rolls are held in position by the journals acting radially upon the lump and gradually drawing it down to the narrowest space. The material is broken by true crushing by virtue of the superior crushing strength of the cast iron. The rolls consist of a core of soft iron which carries a shell

of chilled iron. One shaft revolves in fixed, the other in movable boxes. The movable ones are held up toward the fixed boxes by means of powerful springs, or also by levers and weights. Power is usually applied by means of gears and pulleys. The shafts are of mild steel.

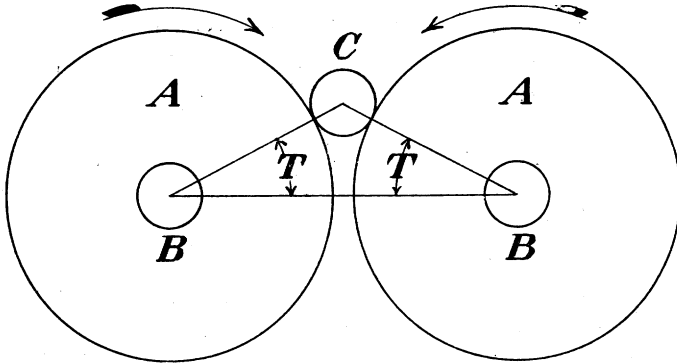


Fig. 34. Diagram illustrating the operation of crushing rolls.

As has been said, rolls are not typical rough grinders, being used only by the Edison Portland Cement Co. These are 5 feet in diameter, with 5 feet face, and are provided with striking pieces, pyramidal in shape, 4 inches high. Below these large rolls smaller ones for intermediate grinding are arranged, 3 feet in diameter and 3 feet long. The rolls make about 150 revolutions per minute. The journals are, of course, extremely heavy. Both rolls are driven by pulleys direct. These may run loose on the shaft, but not until they have overcome the friction of band brakes, which are held up by springs with great tension. These rolls can take a charge of about 5 tons, and the capacity when running 150 revolutions per minute is approximately 300 tons per hour. However, on dumping in a charge, the speed is decreased and it takes some time to pick up again, requiring about 80 horsepower to do this. This change of retardation and acceleration takes up about one-sixth of the time. The average power consumed is 55 horsepower. The distance between the striking knobs is 10 inches.

INTERMEDIATE GRINDING MACHINES.

Of machines of this kind we have the following types:

1. Rolls.
2. Disintegrator.
3. Kent mill.
4. Ball-mill.
5. Dry pan.

Rolls.—It cannot be said that rolls are now used in American cement works with the exception of one, but their general efficiency

for this purpose is so promising that the writer has given them first place in this classification, since it appears to him that these machines do the work of intermediate grinding at the lowest cost. Rolls should not be fed with material over $1\frac{1}{2}$ inches in diameter. It is not an easy matter to give the best size for rolls intended to prepare material for fine grinding, since the velocity, the size of the feed, and the character of the material to be ground are important factors. One large manufacturer of rolls gives 24×14 inches, another 26×14 inches as the best standard rolls. As a whole, larger diameters are to be preferred, since the increased surface means a greater capacity and since they can make a greater reduction with one passage and lastly because they can be run at a greater speed owing to their favorable angle of nip. Yet there must be considered the fact that two small rolls cost less, give a more uniform output, are cheaper to run, and repair and wear more uniformly. But it seems they should not be less than 24 inches in diameter for cement work. The width varies from 12 to 16 inches. Narrower rolls are easier to keep true and by running them faster may have the same capacity as wider rolls. The average peripheral speed of many rolls was found by Professor Richards to be 379 feet per minute, and the average velocity of rolls crushing breaker products 345.7 feet per minute. With a peripheral speed of 300 feet a 24-inch roll would have to run 48 revolutions per minute; with a speed of 400 feet, 64 revolutions.

There is a tendency to advocate high speeds in rolls, as higher speeds make the rolls run more smoothly, and make the action more "free" crushing, and also to use differential rolls, one running faster than the other. Differential rolls have been used to some extent and the experience seems to be that for hard crushing like quartz, differentiation does not help much, but that for limestone and clay the case seems to be different. In one instance, one roll running 25 per cent. faster than the other prevented the formation of ribbons, that is, pressed flakes, while the wear was slightly more, but much more uniform.

The shells have been made of various materials, chilled cast iron, cast steel, chrome steel, hammered steel, manganese steel, rolled steel and forged steel. Chilled iron is cheap, but pits and wears rapidly, chips and is hard to true up. Cost, 2 to 4 cents per pound. Cast steel costs from 6 to $6\frac{1}{2}$ cents per pound, but its surface is not very reliable. Forged steel is the most reliable material and wears uniformly with some attention. Cost, from $6\frac{1}{2}$ to 10 cents per pound. The chrome steel is said to be still better; cost, 10 cents per pound. It is important that the rolls be kept smooth and parallel. This is done by setting the rolls with different laps at the end of every day, say $\frac{1}{4}$ on one end on one day and the same amount at the other end the following day, and turning them down or grinding the surface with emery. This can frequently be done with the rolls in place. If duplicate rolls are used, one can be used while the other is trued up, the changing taking but little

time. This is a considerable advantage over ball-mills or more complicated apparatus. Also when the rolls used for finer crushing have been worn they may be placed in position as coarse rolls. The rolls are held in position by car-wheel springs or rubber blocks, the latter being, however, not suitable for heavy use. The pressures exerted by these springs are indicated by the following table:*

Length of spring in inches.	Amount of compression, in inches.	Pressure exerted by the two sets of springs in pounds.	
		On 26 inch roll.	On 24 inch roll.
7.9375	0.0	0	0
7.4375	0.5	15,000	22,500
6.9375	1.0	30,000	37,500
6.4375	1.5	41,250	52,500
5.9375	2.0	48,750	71,250

The rolls are driven either by direct belting or by belts and gears. For slow speeds the gears are preferred, for higher speeds the belts.

In working with rolls it is absolutely essential that the material to be ground be fed uniformly, and hence the rolls must be provided with simple but efficient feeding devices. The quality of crushing depends to a great extent on the way they are run. When run slowly the material may be crowded so that the fine particles cannot separate from the coarser, and hence are reduced some more by abrasion upon each other. This is called "choke" crushing.

When the speed is increased the fine matter is removed as fast as formed; this is called "free" crushing. This is the usual and most satisfactory method. The power required differs, of course, with the size and work done. On an average according to Richards it is 10 horsepower for 100 tons in 24 hours. The cost of crushing is from 3 to 6 cents a ton for limestone, not including the truing of the shells.

In regard to the space between the rolls, which may be from nothing up to $\frac{3}{4}$ inch, the angle of nip plays an important part. For coarse rolls, a rough rule says that the distance should be one-half the diameter of the largest lumps fed.

The angle of nip is one-half of the angle made by the tangents to the rolls, at the points of contact *aa*, between the lump of rock, *e*, assumed to be a sphere, and the rolls. These tangents form the angle *zn*,

*R. H. Richards, *Ore Dressing*, p. 74.

half of which is called the angle of nip. If the lump is as large as the space between the rolls, the angle is, of course, zero, increasing until the angle is so large that the rolls cannot nip the rock. The angle is a function of the diameter of the rolls, the diameter of the lump and

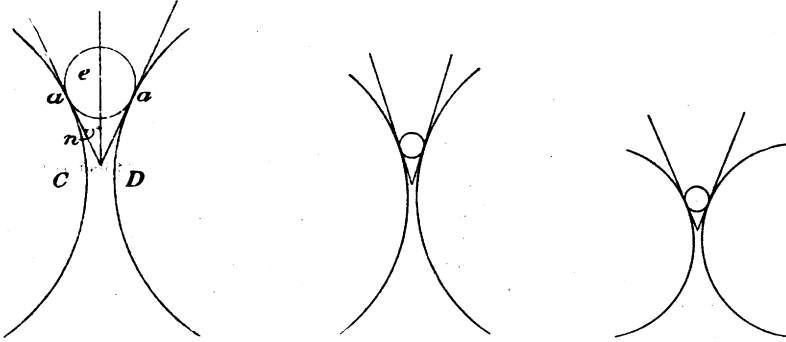


Fig. 35. Diagram illustrating the angle of nip of rolls.

the distance between the rolls. It is diminished by increasing the diameter of the rolls, by increasing the space between the rolls and by decreasing the size of the lumps.

If b = the radius of the sphere to be crushed,

$a = \frac{1}{2}$ the space between the rolls,

n = the angle of nip,

and r = radius of the roll = $\frac{1}{2}$ diameter,

$$\cos n = \frac{r + a}{r + b}.$$

In practice the angles of nip are found to be from $4^{\circ} 16'$ up to $24^{\circ} 5'$, with, according to Professor Richards, an average of about $13^{\circ} 30'$.

The standard angle of nip is given as 16° , which should not be exceeded. Angles smaller than this will have still more favorable action, which, however, is unnecessary. In the following tables the relations between the diameter of rolls, the size of feed and the space between the rolls when the angle of nip is 16° , as given by Richards, are quoted in the table on page 263.

In preparing for the tube mills, the material coming from the breaker should at least make two passages through the rolls, which should not be less than 24 inches in diameter and 12 inches wide. In the accompanying cut, figure 36, rolls are shown which prepare material for the tube mill, taking the crushings of a breaker, but requiring that these should not be more than $\frac{3}{4}$ of an inch in size. This machine has two feed rolls, which distribute the material uniformly over the surface of the roll. Two curved sheets of iron deliver the

Size of Particles, in Inches, Nipped by Rolls of Various Diameters Placed Various Distances Apart,

Diameter of rolls in inches.	Space between the rolls in inches.						
	0.75	0.625	0.50	0.375	0.250	0.125	0.
36.....	2.23	2.10	1.96	1.84	1.71	1.57	1.45
30.....	1.99	1.86	1.73	1.60	1.47	1.34	1.21
26.....	1.83	1.70	1.56	1.44	1.31	1.17	1.05
24.....	1.74	1.61	1.48	1.36	1.22	1.10	0.96
20.....	1.58	1.46	1.32	1.20	1.06	0.94	0.80
16.....	1.42	1.29	1.16	1.03	0.90	0.77	0.64
9.....	1.14	1.01	0.88	0.75	0.62	0.49	0.36

Distance Between Rolls, When Diameter and Size of Particles to be Crushed are Known.

Diameter of rolls in inches.	Size of feed in inches.					
	1.50	1.25	1.00	0.75	0.50	0.25
36.....	0.046		-			
30.....	0.280	0.038				
26.....	0.432	0.191				
24.....	0.512	0.270				
20.....	0.666	0.424	0.031			
16.....	0.822	0.580	0.185			
.....	....	....	0.340	0.101		
9.....	1.193	0.851	0.613	0.372	0.132	

material at the proper place. The rolls are of chilled cast iron, the lower one, being movable, being held in position by strong springs. The upper roll has a greater peripheral speed, being geared in the desired ratio. In the construction of this mill the ratios 1:1.5, 1:2, 1:2.5 and 1:3 are carried out. The capacity of this machine is on the average 8,200 pounds, or 23 barrels per hour, and it requires from 8 to 12 horsepower.

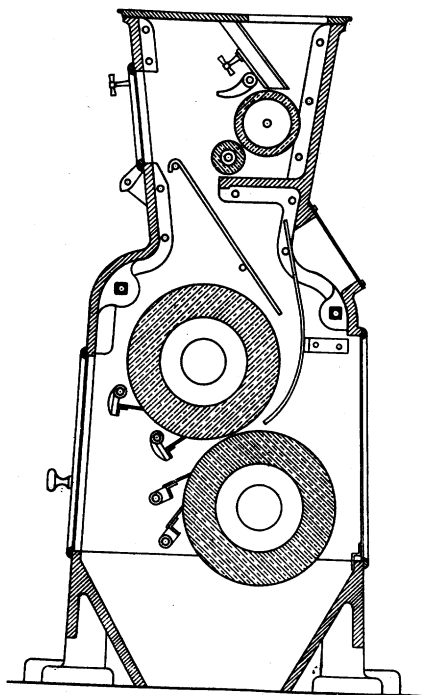


Fig. 36. Intermediate rolls, with feed rolls, for $\frac{3}{4}$ inch material.

It must be repeated that for satisfactory results in intermediate grinding two passages are required, which, however, may be accomplished by means of one set of three rolls, illustrated in figure 39, representing the Edison three high rolls.* These are 36 inches in diameter, 30 inches face, and run 90 revolutions per minute. The shaft L is driven by wooden-toothed beveled gears running in oil. The upper two rolls are driven by friction from the lower and have boxes that are free to slide in vertical guides. Loose sheaves, F, over which run seven passes of $\frac{1}{2}$ -inch wire rope, a bight of the rope passing over the pulley, J, provided with a piston tightener, K, driven by compressed air, furnishes a pressure of 125,000 to 150,000 pounds for crushing. These ropes eliminate nearly all friction except that due to the weight of the three rolls, which amounts to 20,000 pounds. The shells are of soft gray cast iron, costing 2 cents per pound. The edges are beveled to prevent chipping. Each shell is a true cylinder, inside and outside, and is keyed in place. It is 8 inches thick when new and weighs 4,500 pounds. It has to be trued every three days, steel tools being used for truing. The wear of the shells is 0.25 cent per ton. A roller feeder, S, is used. The coarser set of rolls crushes 300 tons of $\frac{1}{2}$ -inch material per hour to pass a 14-mesh screen (0.060x0.5-inch slot).

*R. H. Richards, *Ore Dressing*.

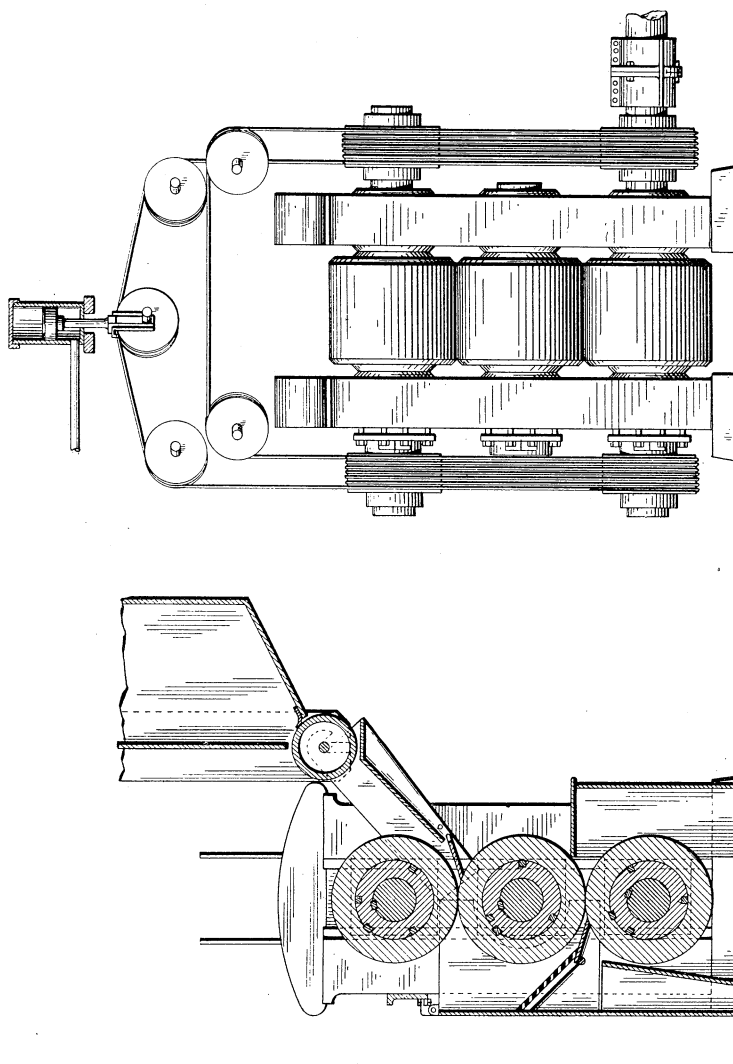


Fig. 37. Three-high rolls of the Edison Portland Cement Company.

The oversize comes back at the rate of 200 tons per hour, making the amount handled 500 tons per hour. The fine rolls crush the 14-mesh material and reduce it to 1-50 of an inch screen at the rate of 135 tons per hour, to which is added the oversize which is returned to the rolls.

Each set of these mills requires power as follows, No. 6 being the coarser and No. 7 the finer rolls:

	When empty, horsepower.	Crushing horsepower.
No. 6 rolls.....	10	260
No. 7 rolls.....	10	150

Edison thus does both the intermediate and fine grinding with rolls.

Disintegrators.—These are true impact crushers and consist essentially of several cages of round bars revolving in opposite directions. The material is fed at the center, is struck by the bars of the inner cage and partly broken and takes a direction tangential to this cage, when it is struck by the bars of the second cage, revolving rapidly in the opposite direction. This type of machine is represented by the Stedman mill and other later makes. By means of a bar projecting into the inner mill, lumps or cakes forming on the inside are broken up. The machines vary in size from 30 to 50 inches, and the bars are from 1 to 1¾ inches in diameter, according to the size of the machine. This machine is well suited for handling almost dry clays, soft shales and coal, for which materials it has a great capacity and is very efficient. It is not so well adapted to heavy grinding. A 40-inch machine will grind 175 to 200; a 50-inch, 350 to 400; a 60-inch, 500 tons of coal per day, requiring 35 to 50, 70 to 100, 100 to 125 horsepower. A 36-inch mill will grind from 90,000 to 140,000 pounds of clay per day, requiring 12 to 15 horsepower; a 40-inch mill will prepare 150,000 to 200,000 pounds of clay, requiring 15 to 20 horsepower.

For heavier work the pulverizers of the hinged hammer type are employed (see figure 38,) and have in a number of cases proven quite successful. In one plant the crushings from the rock breaker 1½ inches in size are taken and reduced so that 84 per cent. passes a 20-mesh sieve, by a Williams pulverizer, showing a capacity of 137 tons in 11 hours, with a consumption of about 75 horsepower. The material is a mixture of limestone and shale. These machines, unlike the Stedman type, do not consist of several cages, but simply of hinged hammers

which revolve around a horizontal shaft, this type of machine being evolved from the simple chain mills which were used some 20 years ago for preparing brick clays in Minnesota and other Western states. The chain mills consisted of heavy chains fastened to a revolving shaft which

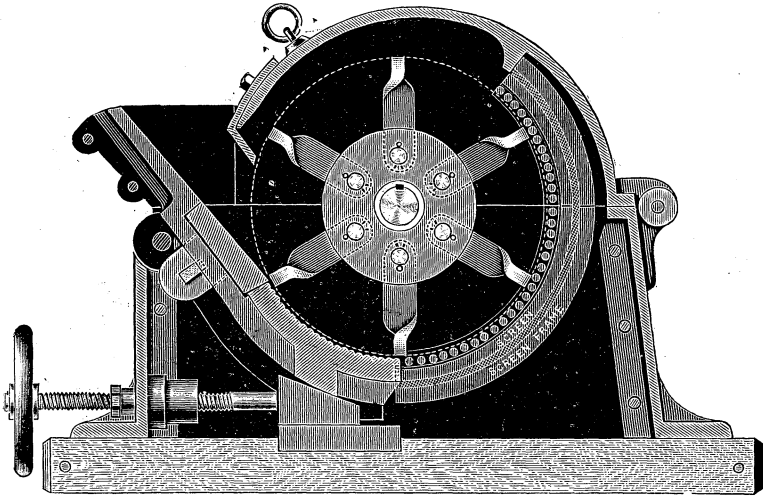


Fig. 38. Disintegrator of the hinged-hammer type, as made by Williams.

whipped the material into small particles. From the standpoint of work accomplished these old homemade mills were quite efficient, but the construction was imperfect in many cases and gave considerable trouble, as was to be expected. The Williams mill, though subject to greater wear than the rolls, and also more expensive as to cost of repair, is a very efficient machine for limestones which are not too hard and dense. When equipped with water-cooled journals, it can work hot materials right from the rotary dryer.

Kent Mill.—This mill (see figure 40) consists essentially of a revolving ring and three rolls pressing against its inner face. The rolls are convex and the ring is concave and tracks on the rolls. Springs support the rolls yieldingly and the rolls support the ring so that the four crushing parts are free to move. The material falls from the inlets on to the inner face of the ring. Centrifugal force holds it there in a layer an inch deep. It revolves with the ring and passes under the rolls. The latter are pressed by the springs outwardly against the rock on the ring with a pressure adjustable to 20,000 pounds, the adjustment being accomplished by means of the screws against the springs. As the rolls pass over the rock they crush it against the ring, while the crushed rock flows off each side of the ring into the casing and falls to the discharge. It is claimed that 90 per cent. of the rock is abraded on itself in crushing, so that the wear on the parts of the machine is quite slight and there is

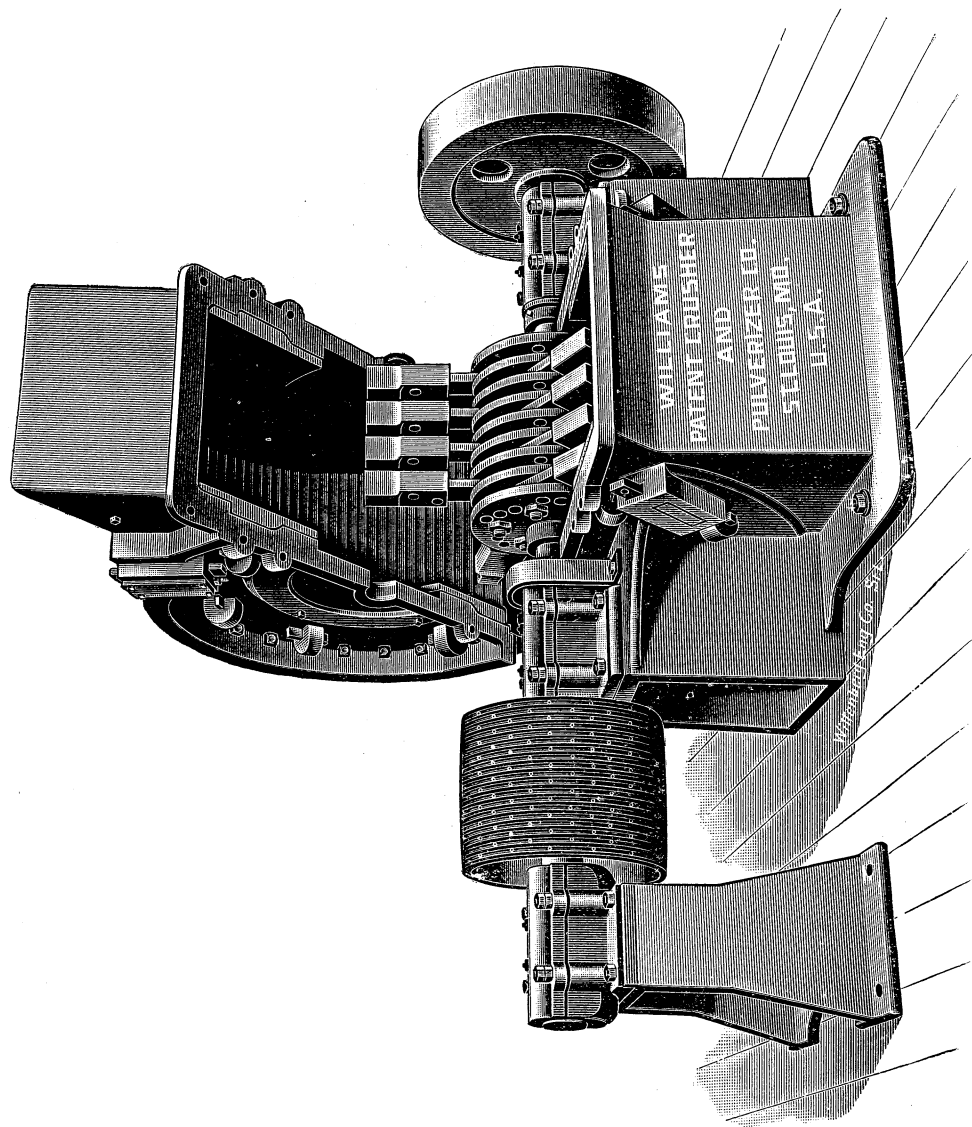


Fig. 39. Williams pulverizer, showing hinged hammers or flails, and grating.

no rubbing on the rock. By attaching separators, either screens or wind separators, to the machine, it can produce material quite fine in size. The speed of the machine is 180 revolutions, its capacity is from 2 to 8

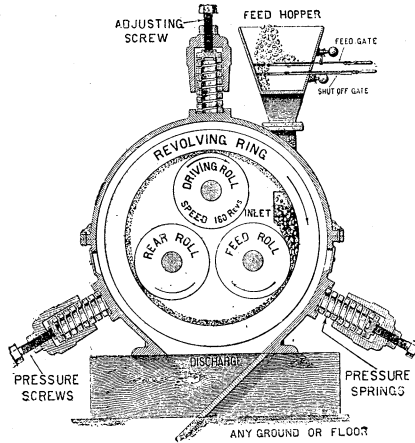


Fig. 40. Cross section of Kent mill.

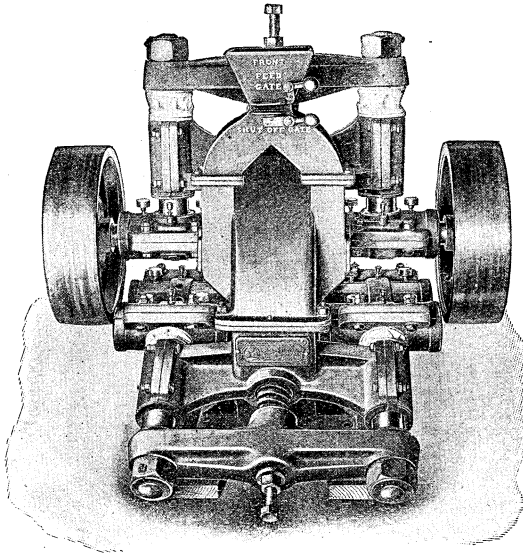


Fig. 40a. Exterior view of Kent mill.

tons per hour according to material and fineness, and the power required is 25 horsepower. In grinding limestone the capacity is quite close to 8 tons per hour, but is considerably less for grinding quartz. The journals

are often provided with water-cooling arrangement, which enables the machine to handle the clinker or material coming from the dryer. The machine, as far as known to the writer, has been very successful.

Ball-Mill.—This mill, in its simplest conception, consists of a cylinder revolving around a horizontal axis with die plates around

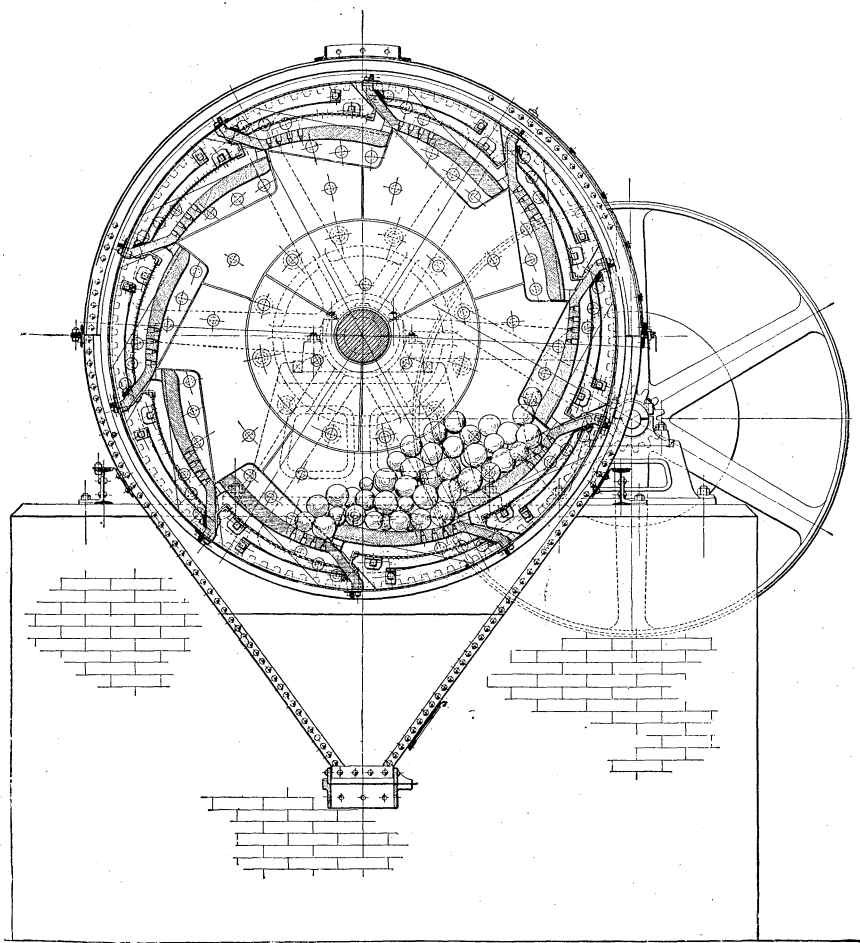


Fig. 41. Ball mill, cross-section.

the circumference. The grinding is done by steel balls. The die ring is composed of perforated chilled iron plates arranged so that each laps the next (figure 41). In this manner steps are formed which give the balls a drop from one to the other, and at the same time the oversize material returned from the screens is admitted into the crushing space at these points. Outside of the die plates coarse screens

are arranged through which the fine material escapes and falls into a collecting bin. The oversize material is caught by deflectors and returned to the crushing chamber. The material is fed through a hopper at one end and leaves through the screens. The machine is also able to do fine grinding if outside of the first screens finer sieves are attached, and the oversize of the fine screens again falls back into

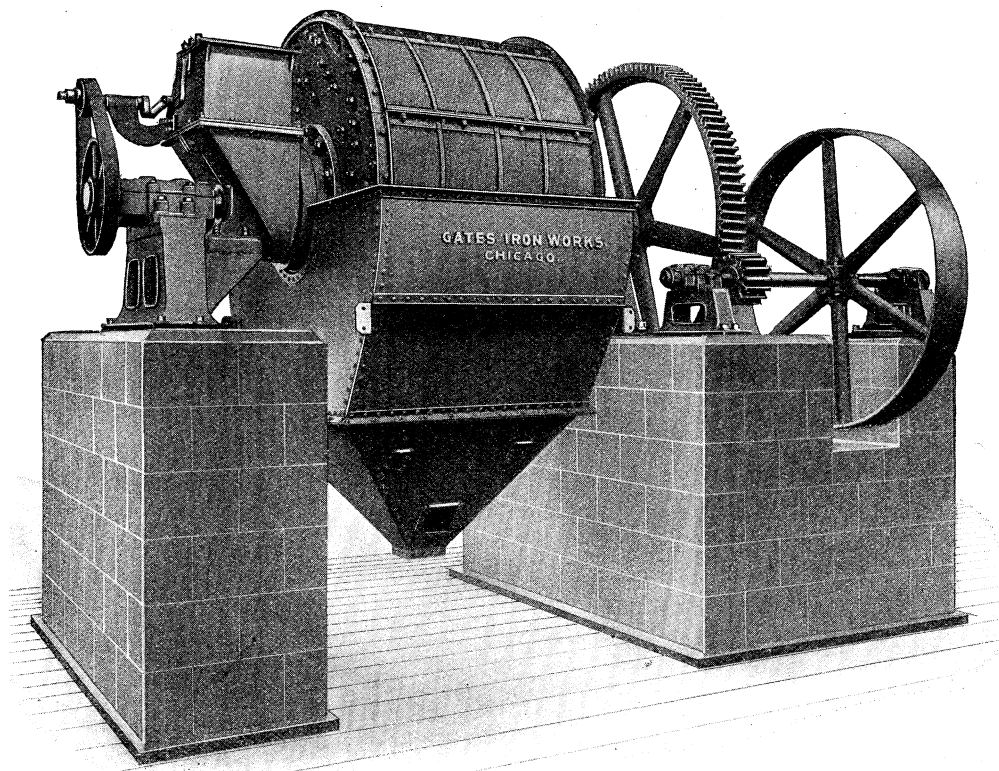


Fig. 42. View of a ball mill, as erected by the Gates Iron Works.

the crushing space. But the capacity is thus decreased very greatly and the efficiency of the machine for this purpose is rather doubtful. The machine, however, works more successfully in this direction if, instead of the screens, there is a strong current of air blowing through the mill, which removes the fine particles constantly as soon as formed, leaving the coarser grains to be ground fine.

The following table gives some data concerning modern American ball-mills, made by the Allis Chalmers Company :

Size No.	Weight without charge of balls. Pounds.	Weight charge of balls. Pounds.	Capacity on Portland Cement clinker. 20 mesh.	Power required.
7	29,500	3,000	12 to 16 bbls. per hour	30 to 40 H.P.
8	41,100	4,500	18 to 24 bbls per hour	40 to 50 H.P.

In starting the mill, from 100 to 120 per cent. additional power is required. When pulverizing to pass all through 20 mesh, from 30 to 40 per cent. will pass a 100 mesh sieve. In grinding limestone, the capacity is greater and averages, for the larger size of mills, 5 tons per hour to 20-mesh sieve. It was found that in grinding 102,400 barrels of cement the steel balls lost 2,959.0 pounds of metal, or 0.139 pounds of metal per ton crushed. At one cement mill in Europe a ball-mill of 64 inches inside diameter, making 17 revolutions per minute, with slits 0.4 inch wide, and requiring 17 horsepower, working a hard limestone, showed an average capacity of 7,700 pounds per hour. At the works of William Krause and Sons, Martin's Creek, Pa., accurate measurements showed the actual average power required to drive one ball-mill to be 39 horsepower. As has been said, some European manufacturers use the ball-mill for fine grinding, separating the fine powder either by means of screens or by blowing air through the material. The first kind is represented by the mill built by Siller and Dubois, in which the first sieve is a steel screen, with one mm. slit perforations, while the fine sieve is a brass screen, 12 meshes to the linear inch. The mill, 64 inches inside diameter, was found to produce with 17 revolutions per minute and 15 horsepower 2,794 pounds of cement per hour, while another mill, of the same make but 72 inches inside diameter, showed an average capacity of 2,970 pounds per hour, requiring 17 horsepower. The fineness of the ground cement is, however, not stated.

The second class of ball-mill with wind separator, having no fine sieves, as built by Pfeiffer, has an average capacity of 1,430 pounds of fine cement, leaving a residue of from 10 to 13 per cent. on a 90-mesh sieve, per hour, requiring 12 to 14 horsepower, or producing 110 pounds of cement per horsepower hour. Since the sieves are very troublesome to take care of and the wind separator does not possess a sufficient capacity, the American practice of using the ball-mill purely as an intermediate grinder without the fine sieves is the best, as it leaves the fine grinding for a typical fine grinding machine. As a type of intermediate grinding machine the ball-mill has the advantage of thoroughly blending the materials, but shows excessive expenditure of power and high repair cost. The fact that it produces 30 to 40 per cent. of fine material does not help the case where this fine size cannot be separated

before feeding into the tube-mill. As a machine it is decidedly inferior to the preceding mills in regard to economy of output.

Dry Pan.—The dry pan, or edge runner, consists of a revolving pan from 6 to 9 feet in diameter, on which run two or more heavy mullers. Around the circumference a space of about 12 inches width is filled with perforated plates. The grinding is done on the solid plate, and the crushed material is scraped on to the perforated plates by fixed scrapers. The oversize material is thrown back on to the center of the pan to be crushed again. This machine is well suited for the intermediate grinding of dry shales and clays, with which a 9-foot pan may show as high a capacity as 100 tons per day, but it is less efficient with hard limestone or soft clays. For softer stones it would show a good output. The iron frame pan does not need much attention and repairs. The chief drawback of the machine is its comparative coarse output, as it cannot be worked with a fine delivery, owing to the danger of choking, and the dust and noise it makes. A 9 foot pan requires from 30 to 40 horsepower.

Arranged in the order of their general efficiency these intermediate grinding machines would range about in the following order: 1, Rolls; 2, Kent mill; 3, Disintegrator; 4, Ball-mill; 5, Dry pan.

FINE GRINDING MACHINES.

Of these we have principally two machines, the tube and the Griffin mill, to consider, the use of other machines, like the buhr or emery mill, having become practically obsolete in American practice.

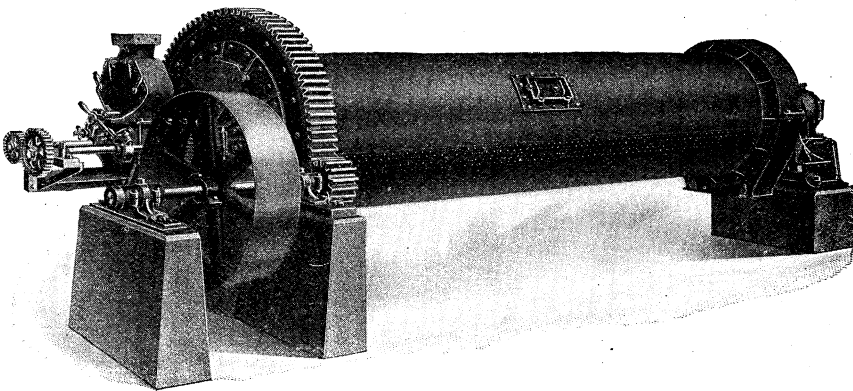


Fig. 43. Tube mill.

Tube Mill.—The tube mill consists essentially of an iron shell from 22 to 16 feet long and from 4 to 5 feet in diameter, filled somewhat above the axis with flint pebbles, imported mostly from Greenland. The

machine is supported by two heavy, hollow trunnions or shafts at the ends, through which the material is fed and discharged at the opposite end. The pebbles are charged by means of a manhole. A screw feeds the material into the hollow shaft. A wing is also arranged just outside of the mill to prevent any pebbles from leaving the mill at the inlet. At the exit end a screen is attached to the opening to prevent any pebbles from leaving at that end.

Just what the real grinding action is in a tube mill has not been understood clearly until recently, and the views in regard to the apparently simple operation of this mill have not been at all well defined. Recently,* however, the operation of the tube-mill was studied in great detail by means of experimental glass mills, and sections covered at the end with a wire screen. In this manner it was possible to study the motion of the pebbles as well as of the material being ground. One experimental mill was 3 feet in diameter inside and was tried with various speeds of rotation. When at rest the pebbles showed a height of 450 mm. The mill was now rotated with a speed of $23\frac{1}{2}$ revolutions per minute, and it was found that the pebbles rolled down the side rather slowly. On increasing the speed the pebbles seemed to loosen, and they rose to a height of 600 mm. with 32 revolutions. The pebbles have no motion until they are carried up the side of the mill, when at a certain height they become loose and drop back to the bottom, describing a curvilinear path which can be noticed quite distinctly. The pebbles farther away from the surface also do not move with reference to the circumference up to a certain height, but their downward path is more difficult to recognize. On increasing the speed to 35 revolutions the content of the cylinder is loosened still more, so that the pebbles rise to a height of 650 mm.; the downward path becomes quite distinct, and the lower pebbles separate in distinct layers. The pebbles of one layer do not mix with pebbles from the other layers. On speeding up the mill still more the pebbles, at 55 revolutions, form a solid ring around the circumference, without any displacement of the balls. With a speed of 34 revolutions a hollow, kidney-like space was observed.

When material is to be ground it assumes the same motion as the pebbles, distributing itself within the spaces so that it is densest where the pebbles are closest, and looser where the latter are loose. The kidney-shape space, therefore, is free from the material—*no rubbing and rolling between pebbles and the charge takes place anywhere except at the point where the pebbles strike the surface on falling from the highest point*. There the pebbles strike with great force and exert an action similar to that of a stamp mill. The pebbles, climbing up the side of the mill, drop away from it as soon as the vertical component of the forces acting upon it is equal to the centrifugal force, or

*H. Fischer, *Zeitschrift des Vereins Deutscher Ingenieure*. No. 13, 1904.

$$mg \sin a = \frac{mv^2}{r},$$

The curvilinear path, therefore, conforms to the equation*:

$$y = x \frac{\cos a}{\sin a} - x^2 \frac{g}{2v^2 \sin^2 a}$$

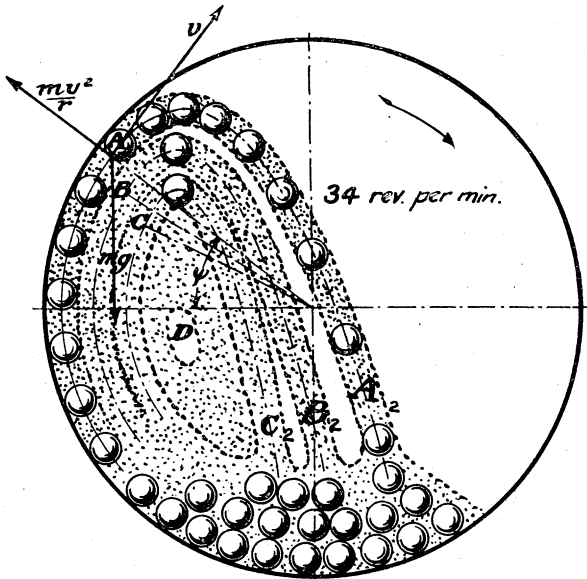


Fig. 44. Diagram illustrating action of tube mill, after Fischer.

In the accompanying figure this path is the line AA_1A_2 . The vertical velocity has negative acceleration, becomes zero at A, and hence the pebbles approach each other, touching at A. The charge is thus forced aside at this point and the path must differ from the theoretical curve owing to the collision of the pebbles. After reaching A the pebbles follow the curve with accelerated velocity, and hence the intervals between them become larger. A second layer of pebbles begins its curvilinear path at B, a third at C, etc. These curves are bound to be less clearly defined, but they frequently separate from each other so markedly that it is possible to see through between them. Most of the grinding effect is thus produced at A_2 , where the motion of the particles to be ground is the resultant of the vertical velocity and the forward motion. A pounding and rubbing action is thus exerted.

The grinding effect depends then on the vertical distance of the drop, the velocity of the drum and weight and number of the pebbles.

*In figure 44 the angle, a , of the formula is indicated by the Greek letter Psi.

The velocity of the drum must be great enough so that the curvilinear motion can be well developed. Harder materials require a higher drop and heavier pebbles than softer, and steel balls can hence do the same work in smaller mills as flint pebbles in larger ones. The greater the number of pebbles, the greater is, of course, the grinding effect. It was also found that the exit of the material being ground was at a much higher point than the inlet, and hence it is not necessary to incline the axis of the mill toward the discharge end.

What causes the material to forward is now the question. As the pebbles descend from their highest point and strike the material to be ground the latter is splashed quite a distance, and if there is much material present a good deal will thus be distributed, while places where there is little throw off but a small amount. In this manner the material is distributed uniformly. This equalization takes place rapidly, as the velocity of the pebbles is quite great, being often as great as the circumferential velocity of the mill. At the exit the ground material is thrown out through the grating, while the pebbles are retained.

The pebbles naturally wear, more or less rapidly according to the conditions under which they work. The statement was made by a builder of cement machinery that one pound of pebbles is used up for 30 barrels of cement clinker. This is certainly too small a figure. The writer was told by others that the cost of pebbles is $\frac{1}{2}$ cent per barrel.

In regard to the capacity of the tube-mill, it can be said that for grinding raw stock it frequently shows a capacity of 6 tons per hour, the size of the mill being 22 feet by 5 feet. For grinding cement this machine has a capacity of from 14 to 20 barrels per hour. The power consumed is 70 to 75 horsepower, though to start the mill a momentary power of about 120 horsepower is necessary. An actual test with five tube-mills, 22 feet by 5 feet, showed a power consumption of 333 horsepower, making 66.6 horsepower for each mill.

The Griffin Mill.—The Griffin mill, shown in figure 45, consists essentially in a horizontal driving pulley (17) from which the shaft (1) is suspended by means of a universal bearing (9). To the lower extremity of the shaft the crushing roll (31) is secured, which is thus free to swing in any direction within the case. The latter consists of the base or pan (24) containing the ring, or die (70), against which the roll works and upon the inner surface of which the pulverizing is done. In dry pulverizing this pan has a number of openings through it downward, outside of the ring, which lead into a receptacle from which the material is taken by a conveyor.

Upon this base the screen (44) is secured which is surrounded with a sheet iron cover (45) and which is not used in wet grinding.

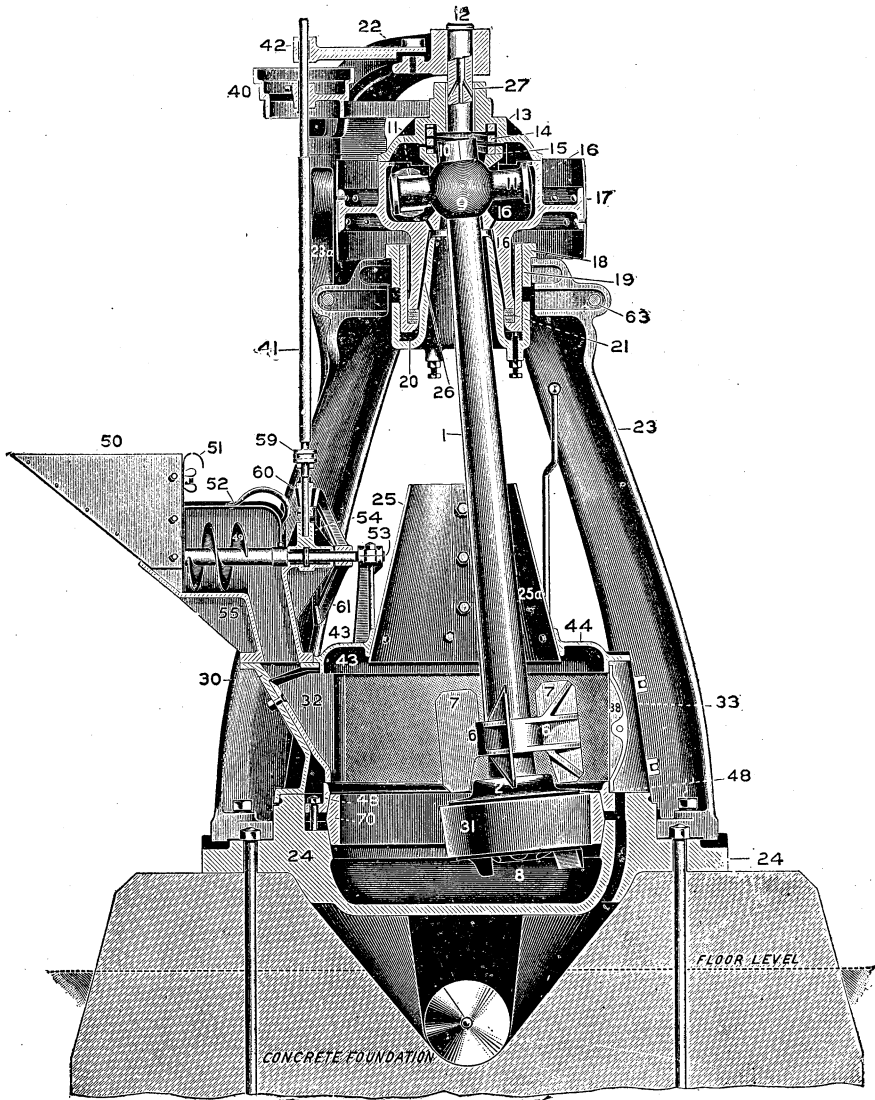


Fig. 45. Griffin mill, cross-section.

To the top of this a conical shield (25) is fastened open at the apex through which the shaft works. Just above the roll is the fan (17) which is used in the dry mill, but not in the wet. On the under side of the roll are shown shoes or plows (5) which are used in both and vary in shape according to the work to be done.

The roll is revolved within the die in the same direction that the shaft is driven, but when coming in contact with the die it travels around the die in the opposite direction from that in which the roll is revolving

with the shaft, thus giving the mill two direct actions on the material to be ground. A pressure of 6,000 pounds is brought to bear on the material to be pulverized between the roll and the die.

When a quantity of the material is fed into the mill, filling the pan as high as the shoes, on the lower side of the roll, they stir it up and throw it against the ring so that it is acted upon by the roll and crushed. All that is sufficiently fine passes at once through the screen, the coarser portion falling down to be acted upon again. The fan attached to the shaft above the roll draws air in at the top of the cone, forcing it through the screens and out into the discharge. A 16-mesh screen delivers a product of which over 90 per cent. will pass a 60-mesh screen.

The roll weighs about 100 pounds and has a diameter of 18 inches. The mill makes 200 revolutions per minute and produces about 3,500 pounds of ground clinker per hour and probably 5,000 pounds of raw stock, consuming 25 to 27 horsepower. Mechanically the machine is very efficient in its action, but being unbalanced, it requires a heavy foundation. Its drawbacks are:

1. A tendency to segregation of the raw stock owing to its centrifugal action.
2. Heavy repair expenses.

Of two particles of the same specific gravity, but of different diameters subjected to centrifugal force the larger one will move toward the circumference more rapidly; of two particles of different specific gravity, but of the same diameter, the heavier one will also move outward more rapidly. On the other hand, in a current of air of uniform velocity the larger and heavier particles will not be carried as far as the smaller and lighter ones. If now in the Griffin mill the force tending to separate the particles by throwing the larger particles farther outward were equal to the force produced by the fan, which carries the finer particles farther, no segregation would take place. Just in how far these forces are balanced in this mill the writer does not know, but it seems that the centrifugal force predominates. The fans also give motion to the particles by impact. It may be that this difference is of no practical importance, but it must stand as being reasonable until contradicted by definite data. It appears, hence, that in a mixture of limestone and clay the lighter clay would be blown away from the stone, while in a mixture of cement rock and limestone of about the same specific gravity no appreciable separation should take place. It must be remembered that a further separating action holds true in the space beneath the pan when the particles drop by gravity into the receiving trough. In this respect the action of the tube-mill seems to be superior to that

of the Griffin mill, though this objection does not hold for a homogeneous material like clinker. The screw conveyor beneath the Griffin mill, to be sure, does some mixing, but it may be doubted whether it does enough of it.

It is also a fact that but few cement mills employ Griffin mills for raw grinding.

The repair expenses of the Griffin mill are said to be higher than those of the tube-mill, although this difference is balanced again by the greater mechanical efficiency of the Griffin mill, which requires less power than the tube mill, the ratio per unit of cement produced being roughly, as 5:7 in favor of the Griffin mill.

HANDLING DEVICES.

In the handling of materials by the dry process horizontally and vertically the following devices may be used:

A. Conveyors.

1. Belt conveyors.
2. Scraping conveyor.
3. Pan, plate and bucket conveyors.
4. Screw conveyor.
5. Jerking troughs.
6. Cars.

B. Elevators.

1. Bucket belt conveyor.
2. Bucket chain conveyor.

Belt Conveyors.—Belt conveyors are used more commonly than other conveyors for longer distances. It is important that they be of good material and first cost should not be made an object in their selection. For carrying crushed or ground material the belt is given a trough-like shape by conical rollers or two rollers inclining towards the middle, the latter being the better way, throwing less wear on the belt. It is better to apply the power at the delivery end than at the receiving end, and the end bearings should be adjusted so as to take up the slack of the belt. These belts work satisfactorily for lengths as great as 500 feet and are the most reliable conveyors; average capacity about 10 tons per hour. They consume but little power for the work done.

Scraping Conveyors.—The scraping conveyor consists of a set of scrapers attached to an endless rope running in a steel-lined trough. This conveyor works satisfactorily only if the sheave-driving pulleys are large in diameter and the rope is run not too rapidly. It takes, however, a great deal of power and is noisy. Chains in place of the rope are much less satisfactory.

Pan or Plate Conveyors.—Pan or plate conveyors consist of steel pans fastened to link belts. These pans may have rollers attached to them which run on a track, the pans moving along between the two rails, or the pans run over fixed rollers. Usually the pans overlap each other so as to avoid spilling the material. The link belt runs over a polygonal sprocket wheel at the ends.

The bucket conveyor consists of a series of buckets suspended from two parallel link belts or from a rope, and which are fed from a bin either automatically, or, if the buckets are large, by a man who works the discharge gate of the bin. The buckets are dumped automatically by a tripper and also right themselves automatically. These conveyors are cheap to maintain and, though periodic in operation, have very large capacities.

Screw Conveyors.—Screw conveyors should in all cases be built of strong material and should not be more than 30 feet long. Their great advantage is the mixing they do. As a conveyor for short lengths they are very reliable if built strong. The consumption of power is very high for the work performed.

Jerking Conveyor.—The jerking or Kreise conveying trough consists of a trough or pipe sloping slightly downward and is given a rapid reciprocal motion, longitudinally, by a disk crank which jerks the material forward, about 350 strokes per minute, with a stroke of $1\frac{1}{4}$ inches. Such a machine, 45 feet long, requiring 2 horsepower, moves about 8 tons per hour. They may be built up to 150 feet long.

For continuous operation the belt conveyor has proven the most satisfactory in handling large quantities.

Cars.—Cars may be used for conveying larger quantities of raw stock, especially from the storage bins to the weighing platform. These are invariably moved by hand and hence the track should be so arranged that it slopes slightly in the direction in which the loaded car is to go. It is always essential that the bins have a decided slope or feed into a conical base from which the material is discharged by gravity into the cars.

Elevators.—Bucket elevators are practically the only means of conveying ground material in the vertical direction. We distinguish two kinds, belt and chain elevators. In the former the buckets are bolted to belts, in the latter they are fastened to chains. Belt elevators can be used for greater velocities than the link belt elevators, which, if run too rapidly, give constant trouble. It should always be made an object to build elevators as nearly vertical as possible, since, when inclined, they are certain to drag and wear rapidly. The elevator boots should be made easily accessible and be perfectly drained. Any dampness is certain to clog and choke up an elevator, especially after standing.

WET GRINDING.

In working wet marls two methods can be pursued. They may be worked in the wet state entirely or dried in rotary dryers and worked like a limestone mixture. The first way is usually followed for several reasons, which are viz.:

1. The mixtures are blended more easily in the wet way.
2. No elevators and conveyors are necessary in handling the raw mixture.
3. There is no expense for fuel outside of the kiln and no dryer to look after.
4. The waste heat which otherwise would escape into the kiln stack is utilized right in the kiln, expelling the water, and though the capacity of the kiln is decreased the process is simplified and no more fuel is used than if the marl were dried. The waste gases, the great source of loss in all rotary kilns, leave at a low temperature.

This applies, of course, only to materials which are dredged wet and naturally contain a large amount of water. It is obvious that the total fuel consumption per barrel is bound to be greater than it would be for dry material owing to the large amount of water present. The wet method has also to contend with difficulties arising from the "ringing" of the kilns, and requires additional power for running the agitators in the vat.

5. The wet process enables the manufacturer to be absolutely sure of his composition by the use of unit tanks and correction vats. The marls are as a rule fine grained materials, and hence no intermediate reduction machinery is necessary. The marl is charged into a wet pan or simply an agitator and mixed with sufficient water to make the desired slurry. Any stones and roots are removed here. The slurry is now pumped by means of piston or centrifugal pumps or, still better, compressed air to a coarse vibratory sieve, which removes any fibrous matter still remaining, and from there runs into a small tank kept agitated thoroughly. At the bottom of this tank a small pug-mill-like mixer is located, above which is a platform carrying the scale by means of which the clay is weighed out. To a certain volume of slurry a given weight of clay is added. This must be dry and pulverized by a disintegrator. From the mixer the combined marl and clay is pumped or run by gravity to the tube-mills. Though the marl may appear fine grained the grinding should not be slighted, since the clay frequently needs to have a most thorough disintegration. Another point to be considered is the presence of the shells so often found in marls. These, being thin and flakelike, are extremely difficult to reduce, and unless disintegrated will form troublesome particles of free lime in the cement which may give considerable annoyance, as the writer has had occasion to observe.

Usually tube-mills 18 feet by 5 feet are employed, although with marls full of shells a 22 foot mill would be none too large. Extreme care should be taken to feed the slurry at a uniform and constant rate, as otherwise all benefits of grinding are thrown away. With fine grained material the capacity of a tube-mill is quite large. At one plant with which the writer is familiar 88 cubic yards of slurry, one cubic yard being equal to from $1\frac{3}{4}$ to 2 barrels of cement, were ground by an 18 by 5 mill in 3 hours and 15 minutes, using 42 horsepower. The slurry left a residue of 4 per cent. on the hundred mesh sieve. It is important to make frequent sieve tests so as to control the grinding closely.

From the mills the slurry is pumped to large tanks holding about 80 cubic yards. These are kept agitated by means of revolving gates, screw propellers or compressed air. The first are the most wasteful of power, while the second are much more efficient. There should be three propellers, one near the bottom, one in the middle and one near the top. The lowest and the middle propeller should work upward, the top one downward. Compressed air at a pressure of from 40 to 60 pounds is said to be the cheapest mode of agitation.

There are two auxiliary tanks which do not contain the regular charge; one holds a slurry high in clay, the other high in lime. If now the slurry in one of the large tanks is found on analysis to be lacking in lime or containing an excess of it, some of the high clay or high lime correction slurry is pumped into the tank, so that after an hour's agitation the corrected slurry is ready for the kiln and the chemist is absolutely sure of his composition. By knowing the volume of the slurry in the regular tank, its composition and the amount of water it contains, and the same facts in regard to the correction slurry, the volume to be added is readily determined. By means of correction tables the amount can be read off at once. No other method of preparation offers such a complete control of the composition. From the storage tanks, the slurry is either fed through a pipe, by gravity, to the kiln, or it is allowed to flow into a pit kept agitated, from which it is pumped by means of a piston pump with adjustable stroke into the rotary.

GENERAL CONSIDERATIONS OF GRINDING.

There is a general tendency to simplify and cheapen the grinding process by the adoption of simpler and less power-consuming machines, like the rolls, and to effect the separation of the coarse particles by means of centrifugal separators or air blasts. This was carried out at the works of the Edison Portland Cement Co., New Village, N. J., on a most elaborate scale. No grinding machines are used but rolls and the fine material is removed by means of an air blast, all the coarser particles being returned to the rolls. It is readily seen that this

must result in a cheap process. But we find that this company uses as raw material a cement rock and limestone whose specific gravities are very close, and it is extremely doubtful whether their process would work with a limestone and soft clay, though it might be applied to a limestone-shale mixture provided their specific gravities were sufficiently alike, and even in this case serious doubts arise. With a cement-rock limestone mixture we have as a base a material already quite close to the Portland cement composition with all of the clay base incorporated with most of the lime. Even if some segregation took place, the resulting mixture, especially when worked and blended, cannot be far from the required composition.

Such a system could be used more generally if apparatus for intimate blending were invented, but so far no machine doing successful and cheap dry mixing has been devised, except for small quantities. There is some hope in this direction by the further application of pneumatic principles, using a differentiation of air blasts.

In the grinding of the raw mixtures it is important to establish the proper rate of feeding and time of grinding by determining the insoluble residue on ignition as described in the chapter on chemical examination. Practically no insoluble residue should be left. In this manner we cannot only see that the mixture is intimate enough, but also that the grinding is not excessive, using more power than is necessary.

In working coarse silicious clays or a clay base of soft clay and sandstone or sand good results cannot be obtained by grinding the complete mixture with the limestone in one and the same tube-mill, unless more tube-mills are installed and the feed decreased. It would seem the best policy in this case to grind the clays separately in a tube-mill for two reasons: first, to avoid the long grinding of the entire large mass, of which the limestone being the largest component is, as a rule, not so difficult to reduce; and, secondly, because the fine particles of limestone and the fine part of the clay would continually tend to envelop the harder fragments of quartz and thus prevent their complete reduction. The clay after its preliminary grinding would then be ground and blended with the limestone in the regular tube-mills.

It has been frequently asserted by champions of the marl process that it is impossible to grind limestone and clay mixtures as fine as the marls occur in nature, and hence the product of the latter is bound to be intrinsically inferior. Also, it has been claimed that wet grinding will produce finer products than dry grinding, and that even the shapes of the quartz grains will be different when ground wet than when ground dry.

In order to examine the relative fineness of the different raw mixtures, the writer undertook the mechanical analysis of a number of samples taken from various machines used in mills visited by him. The analysis was made by the suspension method already described.

Number.	Materials used.	Fine grinding machine used.	Residue on 80 mesh sieve.	Residue on 120 mesh sieve.	Residue on 200 mesh sieve.	Grains average diameter 0.00210 in.	Grains average diameter 0.00088 in.	Grains average diameter 0.000435 in.	Finer than last size.	Total amount finer than 200 mesh.	Remarks.
1	Limestone and shale.....	Emery mills.	per cent 2.00	per cent 8.89	per cent 4.85	per cent 16.93	per cent 8.96	per cent 8.70	per cent 48.68	per cent 83.27	Ground dry.
2	Cement rock and limestone.....	Griffin mills..	16.38	11.57	4.75	16.21	13.29	7.61	30.17	67.28	Ground dry.
3	Limestone and lay	Tube mill. ..	3.03	7.42	3.68	23.77	17.52	10.26	34.33	85.88	Ground dry.
4	Limestone and clay	Tube mill. ..	7.40	9.56	2.48	17.72	8.96	8.83	45.05	80.56	Ground wet.
5	Marl and clay	Tube mill. ..	3.04	5.50	5.21	21.31	12.63	9.61	44.72	87.27	Ground wet.
6	Marl and clay	Tube mill. ..	30.46	4.28	2.17	6.73	10.61	9.31	36.44	63.09	Ground wet.
7	Marl and clay	Tube mill. ..	2.48	5.23	2.47	16.14	14.22	12.01	47.46	89.83	Ground wet.
8	Marl and clay	Tube mill. ..	26.74	6.99	2.13	10.52	9.77	7.67	36.18	64.14	Shells in marl quite evident.

It is thus seen that in these raw mixtures there is practically no difference in the fineness attained in grinding between limestone-clay and marl mixes. The figures of the analysis themselves are of interest inasmuch as they show how far the fineness is really carried in practical work. The last column of figures showing the amount of matter finer than 200 mesh is the best gauge of the fineness.

The question of the grinding of quartz being an interesting one from the practical standpoint, it seemed worth while to the writer to determine on a small scale, if possible, how far the grinding of quartz has progressed during a certain period of time during which the same weight of a limestone clay mixture has been ground to the desired fineness, passing through a 100-mesh sieve and leaving no residue after ignition and treatment with hydrochloric acid and sodium carbonate solutions. This work was carried out by taking 25 pounds of a raw cement mixture consisting of Wellston limestone and silicious clay obtained from a drift deposit on the State University campus passing a 10-mesh sieve and grinding the mixture in an iron ball-mill with 136 pounds of flint pebbles till it answered the above tests, which required four hours. This time could thus be taken as representing the time necessary for the thorough grinding of a commercial cement mixture.

A charge of 25 pounds of glass sand whose mechanical analysis was as given below was placed in the mill with 136 pounds of pebbles and ground somewhat over four hours.

	Per cents.
Residue on 40 mesh sieve.....	49.16
Residue on 60 mesh sieve.....	33.26
Residue on 80 mesh sieve.....	6.82
Residue on 100 mesh sieve.....	6.64
Residue on 120 mesh sieve.....	1.77
Residue on 150 mesh sieve.....	1.03
Residue on 200 mesh sieve.....	0.29
Finer than 200 mesh sieve.....	0.54

There was only 0.83 per cent. of chemically available material in this sand. At intervals of 15 and toward the end of 30 minutes the mill was stopped and a small sample removed for mechanical analysis. This was carried out as described in Chapter III. Everything passing the 150 mesh sieve was called chemically available, as previous experiments had shown that quartz of this fineness was rendered soluble in acid and alkali by ignition with lime.

The results of these experiments are shown by the accompanying curve, figure, 46, in which we find that in 250 minutes the sand contained 82½ per cent. of chemically available material. This means, therefore, that in the time required to grind 25 pounds of a limestone clay mixture sufficiently fine, the same amount of quartz sand ground under the same conditions (27 revolutions per minute of the mill already described elsewhere) had but 0.8 of the quartz chemically available.

CURVES SHOWING PROCESS OF GRINDING QUARTZ SAND IN A DRY BALL MILL.
136 LB. FLINT PEBBLE, 25 LB. OF QUARTZ.

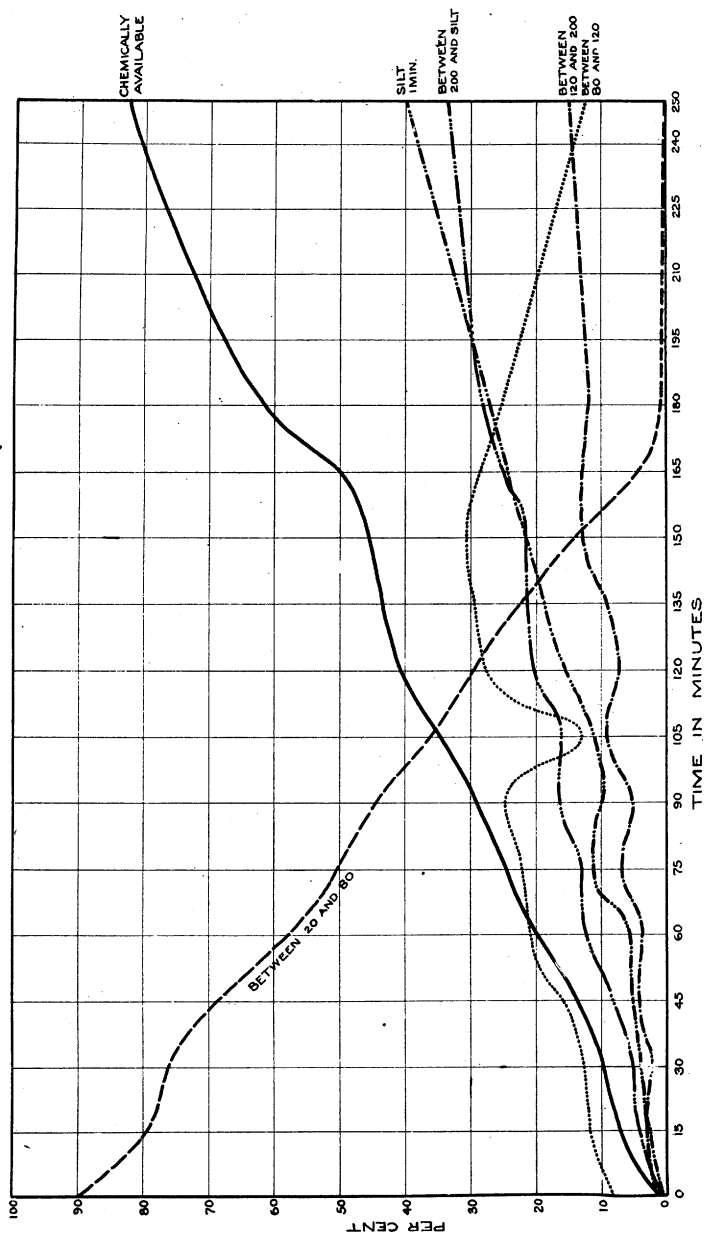


Fig. 46. Curve, showing rate of reduction of quartz in fine grinding.

This tends to show that it is possible to grind sand or sandstone sufficiently fine for cement purposes, if either more time is allowed for the grinding or it is carried on separately. It will be noticed that the curve of "chemically available" material does not change materially in its slope, which seems to indicate that in 5-4 the time, that is, in about 310 minutes, practically all of the quartz would have been rendered chemically available. The most important fact brought out by this experiment is this uniform slope, for if the output of really fine material were to decrease as the grinding, that is, the bulk of fine particles increases, the feasibility of the fine grinding would seem more or less problematical. It was intended to carry out the experiment with coarse quartz sand, clay and limestone mixtures, but the breaking of the mill due to unusually severe work put a stop to the experiments.

CHAPTER VIII.

THE BURNING OF PORTLAND CEMENT—THE GRINDING OF THE CLINKER AND GENERAL ARRANGEMENT OF PLANTS.

The raw mixture, fine ground, is now ready for burning, which is done, in American practice, almost exclusively in the rotary kiln, since this is by far the most economical and efficient apparatus for this purpose, in spite of its high fuel consumption. It consists essentially of a long tube of sheet steel, about 7-16 inch thick, usually 60 feet long and six feet in diameter, which is lined with fire brick forming a layer decreasing from 9 down to 4 inches in thickness. The tube is provided with two flanges 5 inches wide, one 9 feet from the lower end, the other about 11 feet from the upper end, each running on two pairs of cast steel wheels, 22 inches in diameter and 6 inches face, which are apart a distance of 46 inches from center to center.

The kiln is rotated by means of a cast iron or steel gearing about 24 feet from the upper end, which is provided with expansion leaves, is 74 inches in diameter, has a 6 inch face, 3 inch pitch and 75 teeth and consists of two parts. At the lower end is located a heavily bricked head supported by four cast iron wheels which vary from 1 to 2 feet in diameter and which enable the head to be moved away from the kiln. The shell is riveted flat on the inside, the rivets being $\frac{3}{4}$ inch and spaced 4 inches from center to center. The lining consists of the best grade of firebricks in the hottest zone of the kiln and the so-called blast furnace grade in the cooler portion. The stack is from 60 to 80 feet high, and 3 to 4 feet in diameter; the lower forty feet consist of 3-16 inch sheet steel, the remaining part of $\frac{1}{8}$ inch sheet steel with 7-16 inch rivets.

According to the different requirements of different plants, the kiln is revolved slower or faster, the average velocity being about one revolution per minute. The slope of the kiln is about 3 feet in 60 feet. By means of a single pipe, powdered coal dust is blown into the kiln, the blast being furnished by a fan blower. The ground mixture is introduced either through a pipe, if slurry, or by means of a screw conveyor, if dry.

The kilns are sometimes arranged with a tapered receiving end for dry materials. The kiln is also provided with a speed regulator, of which there are several types on the market.

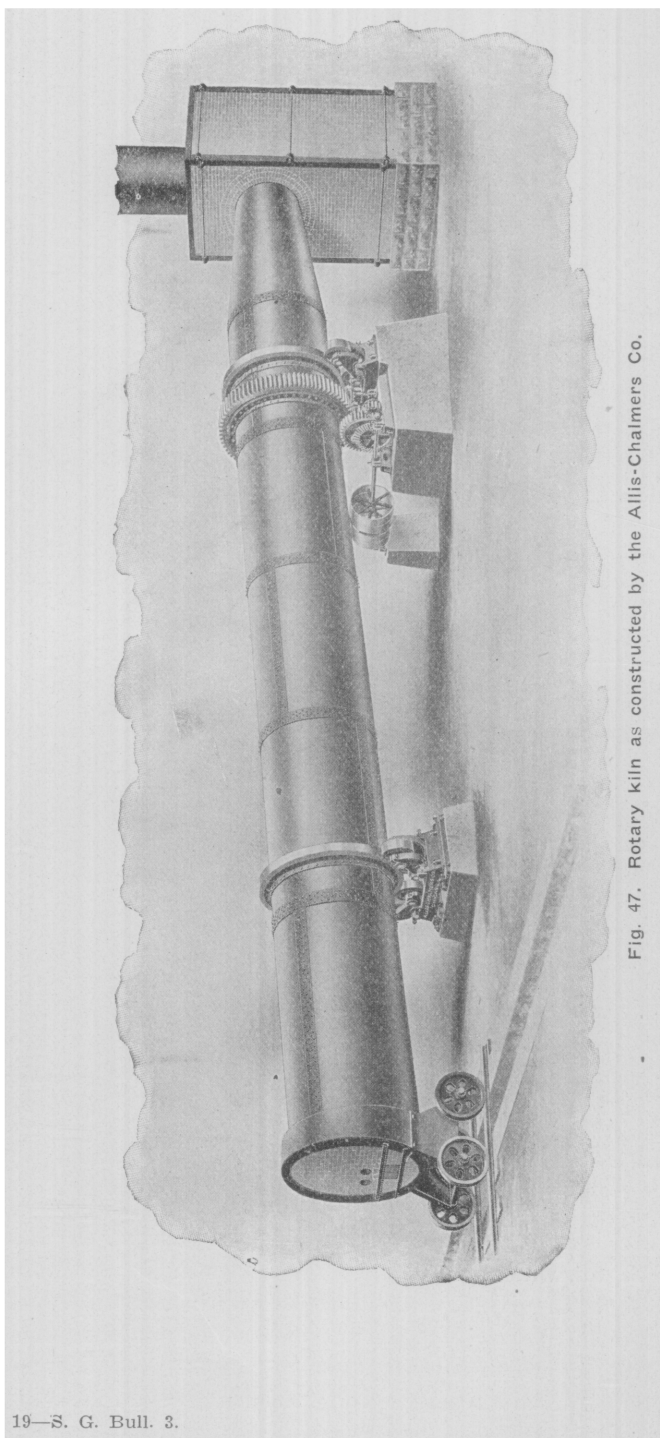


Fig. 47. Rotary kiln as constructed by the Allis-Chalmers Co.

The illustration on page 289 shows a modern rotary kiln as erected by the Allis Chalmers Company.

The burning process proper is extremely simple. A fire is started with wood and as soon as this is burning briskly coal dust is blown in, in gradually larger quantities till the desired heat is being produced. The

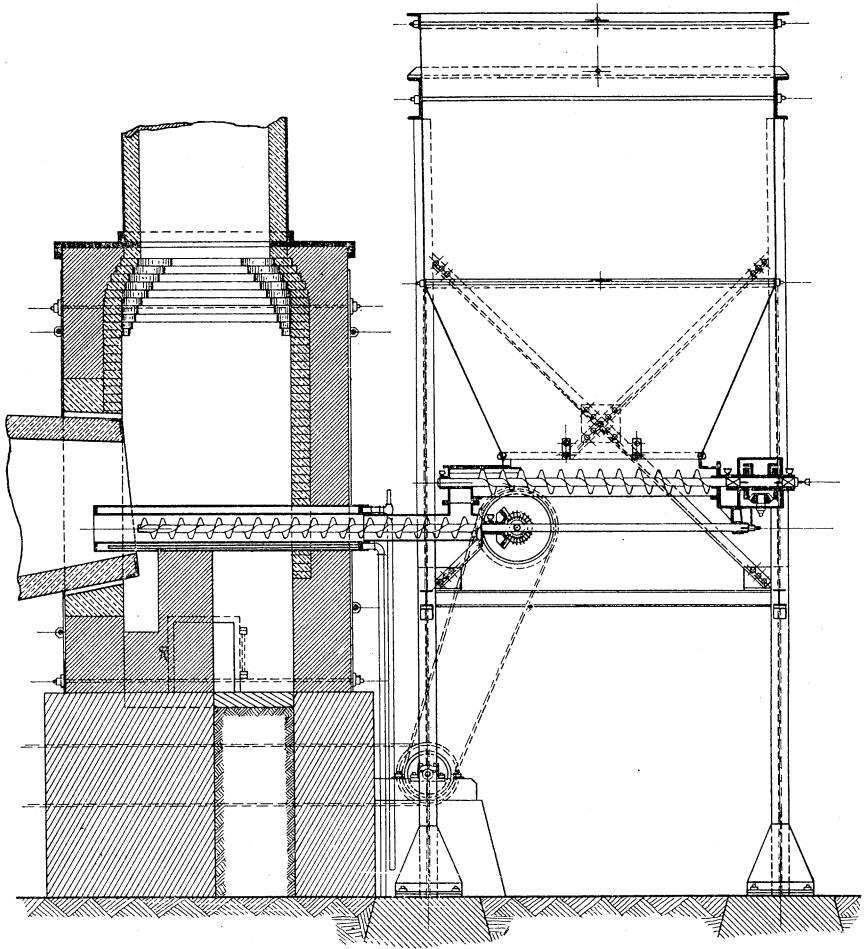


Fig. 48. Diagram, showing method of feeding a rotary kiln, with dry powdered cement batch.

cement mixture is then fed to the kiln in a regular supply and the burning thus begun, which is kept up for six days in the week until the lining shows signs of giving way. The clinker, in the shape of black roundish balls from the size of a pea up to that of a walnut, often consisting of aggregates which cling together in clusters, is discharged in a regular stream. The air required for combustion enters partly with

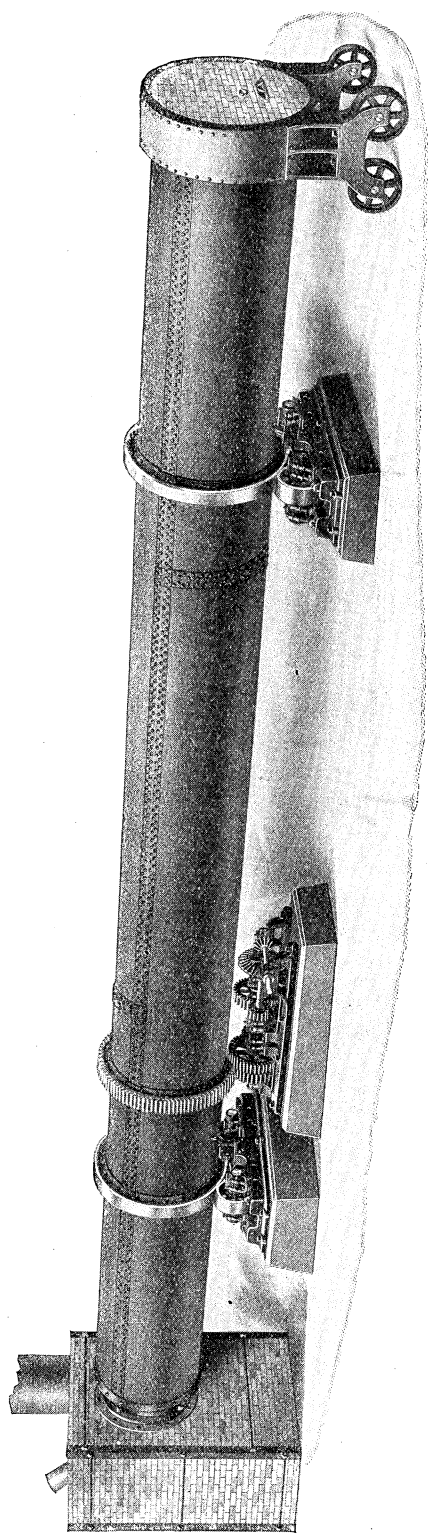


Fig. 49. Rotary cement kiln, as constructed by the Bonnot Co., Canton, Ohio.

the blast carrying the coal dust, partly through air supply doors in the kiln head and partly through the opening through which the clinker is discharged. Its supply is solely gauged by the appearance of the clinker, that is, as much or as little air is used as will produce the right kind of clinker, irrespective of the coal consumption. The burner has as many as three means of regulation available for controlling the burning process, namely, the speed of the kiln, the rate of feeding the mixture and the rate of feeding the coal dust. In some plants the mixture feed cannot be regulated so as to insure a steadier output, thus compelling the burner to work up to a definite adjustment. This seems more satisfactory, as with three means of regulation an indifferent burner is liable to become confused and does not do justice to the kiln, though it cannot be denied that in the hands of an expert burner the best results are obtained with three means of regulation. With a rapid cement feed the burner, on the other hand, desires to be on the safe side by using plenty of coal, thus tending to use more fuel than is necessary. The proper temperature is gauged by the appearance of the clinker as it passes down the kiln.

Two means of adjustment have so far not been made use of to any extent, namely, the regulation of the blast pressure and of the direction of the coal dust blast into the kiln.

The first means imply the use of a higher pressure, which can be cut down as desired, or the use of a coal blast pipe with a steady pressure and an auxiliary air pipe which may be regulated to suit the various conditions. At the works of the Edison Portland Cement Co., high air pressure is employed, as high as 60 pounds to the square inch, the writer was informed.

The second method of bringing in the auxiliary air has been strongly recommended by several cement men. In this case an air chamber is built into the head from which the air flows upward, impinging upon the stream of coal dust at an angle and thus increasing the volume of the flame from a narrow to a larger zone.

In regard to the direction of the coal dust blast Dr. Valeur reports some interesting observations. In a kiln rotating in the direction of the hands of a clock the clinker rises on the wall of the left side of the kiln while the right side is practically bare. The blast was introduced at the left side of the kiln and assumed a rotary or gyratory motion. After striking the bare wall of the right side of the kiln it again returned to the left side. At the place where the flame strikes the bare wall of the kiln it softens the brick which, hence, when coming in contact with the clinker, are worn by abrasion and succumb very rapidly. This experience caused Dr. Valeur to adjust the angle of the blast so that it struck the left side of the kiln at a definite distance, $4\frac{1}{2}$ feet from the end, with

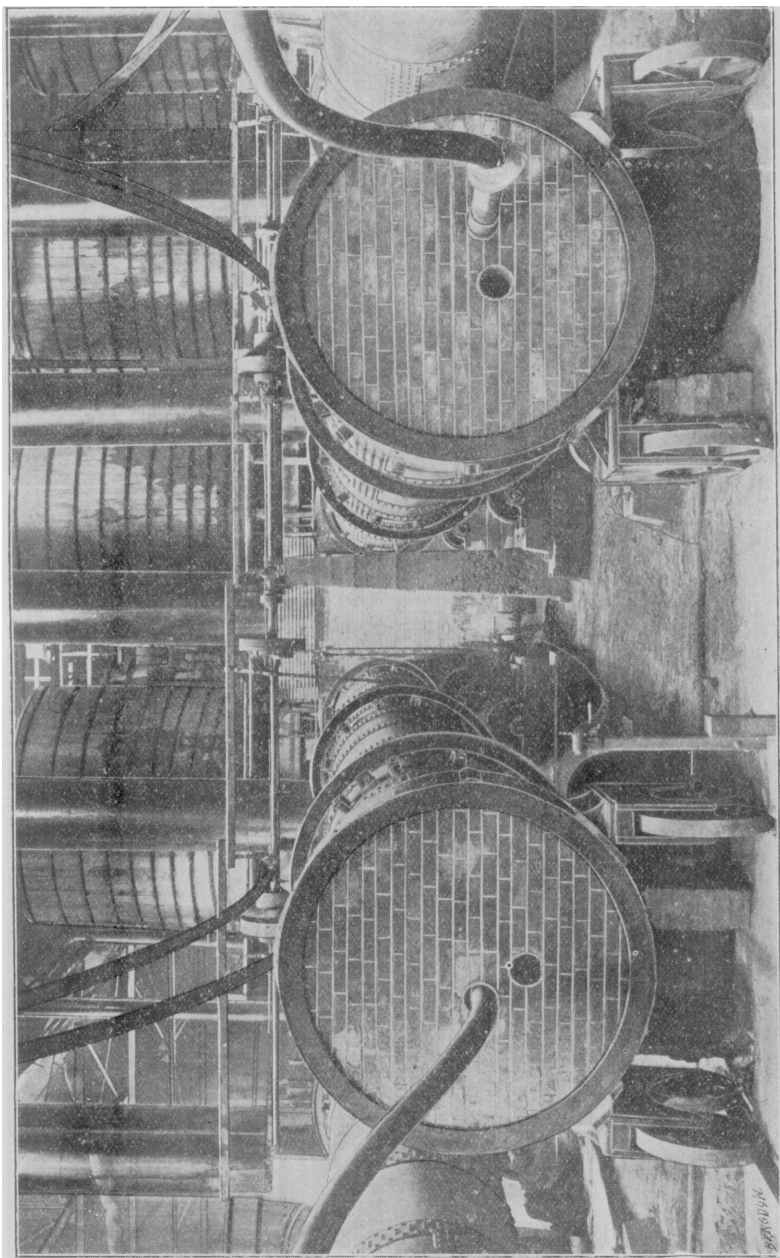


Fig. 50. View of two rotary kilns, at the furnace end, showing the pipes through which the fuel is supplied.

which the flame was not deflected at all, but followed the left side of the kiln throughout. In this manner he succeeded in increasing the output from 140 to 200 barrels per day and the coal consumption was lowered from 138 to 110 pounds per barrel. The saving in kiln repairs also was quite striking, it being reduced to two repairs per year. Likewise the

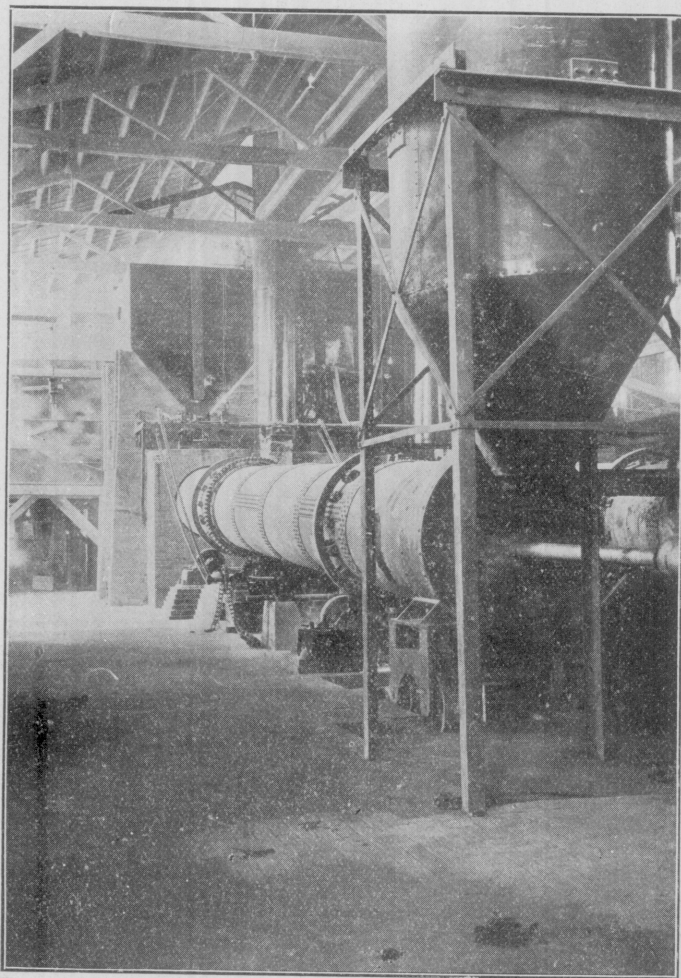


Fig. 51. View along the side of a rotary kiln, showing the coal-dust storage tank, and pipe through which the dust is being blown into the furnace. The cement-batch tanks in the distance at the other end of the kiln.

formation of rings, the wet method being used, was reduced to a minimum, so that the kiln could be operated for two weeks without stoppage on this account.

Coal Used.—The kind of coal used is of great importance inasmuch as it must contain the proper amount of volatile combustible matter in order to ignite quickly, at the proper distance, so that the maximum temperature is produced at the right point, about $10\frac{1}{2}$ feet from the lower

end of the kiln. If a coal is used which ignites less readily, the ignition takes place too far up in the kiln and the zone of maximum temperature is therefore too far removed and causes ringing and other difficulties, besides making it difficult to watch the vitrification of the clinker at close range. And again, this moving back of the clinkering zone causes the waste gases to leave at a higher temperature with subsequent greater loss of heat. Probably one of the best coals used for this purpose is the Pittsburg coal of the following composition:

Ultimate Analysis.

	Per cents.
Carbon.....	75.24
Hydrogen.....	5.18
Oxygen.....	8.24
Nitrogen.....	1.51
Sulphur.....	1.79
Ash.....	8.02

Proximate Analysis.

Moisture.....	1.37
Volatile combustible matter.....	36.80
Fixed carbon.....	53.81
Ash.....	8.02

The average composition of a good West Virginia coal from Fairmont largely used for cement burning is:

Ultimate Analysis.

	Per cents.
Carbon.....	73.60
Hydrogen.....	5.30
Nitrogen.....	1.70
Sulphur.....	0.75
Oxygen.....	10.00
Moisture.....	0.60
Ash.....	8.05

Proximate Analysis.

Moisture.....	0.60
Volatile combustible matter.....	38.10
Fixed carbon.....	53.24
Ash.....	8.06

The chief considerations to be taken into account when selecting a cement coal are:

1. Heating power must be sufficiently high.
2. Sufficient amount of volatile combustible matter.
3. Low sulphur content not more than 2 to 2½ per cent.
4. Not more than 10 per cent. of ash.

The reasons for requirements one and two are, of course, obvious. In regard to the sulphur it must be said that it may give rise to considerable trouble if too great in amount. By keeping the fire reducing in character much of the sulphur may be carried off in the gases without absorption by the cement and in exceptionally bad cases a small amount of coal low in sulphur may be ground with the raw mixture. This, together with the reducing conditions and the high temperature, will keep out any dangerous amount of sulphur. Oxidizing burning conditions, i. e., firing with excess of air, will invariably tend to retain a great deal of the sulphur of the coal in the cement. Searching investigations in regard to the absorption of sulphur by cement in the rotary kiln have not yet been carried out.

There is no practical method for eliminating the sulphur from the coal. Even when coal is converted into gas fuel, which admits of a treatment with chemical reagents, through scrubbing apparatus, it cannot be wholly desulphurized at reasonable cost.

Since in the white hot kiln, the fine particles of coal ash are fluxed or fused into the cement and become a part of it, it is evident that its importance depends on the composition as well as on the amount. A silicious ash is bound to give rise to more serious disturbance than a basic ash. But we are able to eliminate the ash, if necessary, by gasification, a perfectly practical procedure. In this manner many coals otherwise unsuitable can be used successfully. This problem is sure to be met by some manufacturers and the use of very high-ash coals, obtained at a low cost, will thus become possible.

Producer Gas.—It has been said that fuel gas has too low a calorific power for use in the rotary kiln, but this opinion is evidently wrong for fuel gas made under proper conditions. The production of generator gas is not a process as thoroughly understood by many who operate generators as would be desirable, and hence the results are often extremely irrational. For firing a rotary kiln bituminous coal is best used in the generator. In brief, the latter consists of a circular shaft (see figure 52) provided with a flat grate and a coal charging device on top. After a fire has been built up, coal is charged till a heavy bed of ignited coal is formed with a comparatively cool zone on top. A certain amount of steam is blown in; the amount must be so regulated that not more than 800 pounds of steam is brought in for each ton of carbon. Some generators are provided with a revolving grate which ejects the ash and coal clinkers mechanically. The Taylor generator, which represents a good sample of a modern gas producer, is of this construction. The steam jet not only introduces steam, but also regulates the amount of air taken into the generator. We can distinguish three zones in the producer:

- A. The ash zone.
- B. The combustion zone.
- C. The distillation zone.

It is important that the mass of coal be kept from fissuring, since this would tend to produce carbon dioxide, thus lowering the heating value of the gas and increasing the generator temperature. The steam is introduced for the purpose of keeping the generator temperature down, this being an extremely essential point upon which the success of the

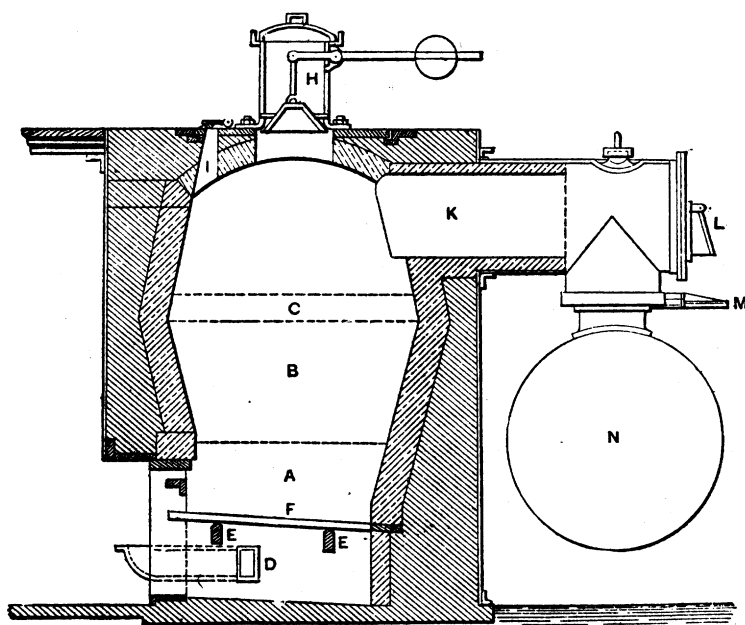


Fig. 52. Cross-section of fixed grate gas producer.

generator hinges. The steam is decomposed into oxygen and hydrogen, the gas being thus enriched by the presence of the latter gas. At the same time it is essential that not too much steam be added, or the temperature would fall too low for its decomposition and it would merely dilute the gas instead of enriching it. The following analyses represent an average composition by volume of bituminous producer gas:

	Per cents.	
Carbon monoxide.....	23.7	27.0
Hydrogen	8.0	12.0
Marsh gas.....	2.2	2.5
Carbon dioxide.....	4.1	2.0
Nitrogen	62.0	56.5

The calorific power of bituminous gas is on the average 2809 B. T. U. per pound or 187 B. T. U. per cubic foot. The efficiency of the conversion from the coal to the gas is claimed to be 88 per cent. The specific gravity is nearly the same as air, about 0.97. In examining the

efficiency of a producer the amount of steam in the gas should be frequently determined by absorption and weighing the condensed steam. By keeping the generator as cool and the amount of steam as small as possible, it will give no trouble as a rule. It is also of importance to have the generator sufficiently large so as to supply all of the gas needed with ease, without forcing the combustion too rapidly. It is much better to have two larger generators in place of four smaller ones. The gas should be conducted into the kilns through as short a flue as possible, so as to avoid the loss of the tarry matter which otherwise deposits. Gas firing should invariably be connected with regeneration, that is, using the waste heat of the kiln for pre-heating the air to be mixed with the producer gas. Without regeneration the system of gas firing loses much of its value.

No one should employ producer gas if it is at all possible to use suitable coal for direct firing. Gas firing can never become fully as efficient as dust coal firing, as certain losses, both chemical and mechanical are bound to occur. Some of these heat losses of a gas generator are shown in the following tabulation:

Assumed total calorific power of coal, 8,198 calories per kilogram.

	Calories.	Per cent of total heat generated.
Potential heat lost in ash or carbon.....	483	5.9
Latent heat of volatilization.....	600	7.3
Decomposition and heating of steam.....	356	4.3
Radiation and conduction.....	355	4.3
Sensible heat of gas.....	1,085	13.2
Total loss of heat.....	2,879	35.0

Some loss would occur under these same heads in direct firing, but not in as great degree, the difference being about 15 per cent. in favor of direct firing.

Ohio Coals.—It is impossible to give a discussion of the available Ohio coals in this report, a subject so admirably treated by the late Dr. Edward Orton, Sr., in his various reports of the Ohio Geological Survey. The writer will restrict himself to giving the analyses of a number of coals more especially available for cement burning.

The analyses on the following table showing the calorific powers have been obtained through the kindness of Prof. N. W. Lord in advance of his report on the constitution and chemical properties of the Ohio coals to be published by this Survey. Though some of its best coal fields have been largely exploited, Ohio still has large quantities of coal suitable for cement purposes.

Location.	Moisture.	Volatile combustible matter.	Fixed carbon.	Ash.	Sulphur.	Calorific power.
Peacock Mine, Pomeroy.....	4.75	39.15	50.35	5.75	0.77	
Minersville.....	3.50	40.17	47.89	8.14	1.96	
Syracuse.....	5.04	37.58	51.82	5.56	1.49	
Mineral, Athens Co., No. 6...	6.80	36.90	48.25	8.05	2.14	6,794
Continental Coal Co., Bren-						
holt's No. 6.....	7.55	34.03	52.57	5.85	0.77	6,950
N. Pittsburg Coal Co., Buch-						
tel.....	7.45	35.01	52.73	4.81	0.66	7,057
Sand Run, Hocking Co., 6...	7.40	34.17	53.43	5.00	1.06	7,027
Continental Coal Co., Glous-						
ter, No. 6.....	7.14	34.22	51.92	6.72	1.65	6,863
Continental Coal Co., No. 6						
Jacksonville.....	7.28	32.38	53.61	6.73	0.86	6,894
Corning, No. 6.....	6.79	35.45	51.85	5.91	1.00	6,903
Bird's Run, Guernsey Co. No. 6	10.93	34.00	48.43	6.64	2.03	6,133
Upson's Mine, Shawnee.....	7.76	33.50	51.27	7.47	1.45	6,772
Luhrig Mine, Athens Co....	6.17	36.40	49.61	7.82	0.90	6,868
Meigs creek coal.....	3.18	38.31	50.10	8.41	1.28	

Fuel Consumption in the Rotary Kiln.—This is a large item and it is in this respect that the rotary kiln shows to its poorest advantage.

S. B. Newberry has calculated the amount of coal required under different conditions, burning wet and dry mixtures, assuming that the cement has an average composition and requires a burning temperature of 2500° F. The coal assumed to be used is Pittsburg coal with a calorific power of 13,400 B. T. U., requiring 10.2 pounds of air per pound of coal. The calculation is based on the barrel as a unit.

Burning a dry mixture, a rotary kiln with the waste gases escaping at 1500° F., and with theoretical amount of air, requires per barrel 628,902 B. T. U. or 66.9 pounds of Pittsburg coal; with 50 per cent. air excess 82.2 pounds of coal are needed. The actual amount of coal required in practice is 110 to 120 pounds per barrel.

The rotary kiln fed with slurry containing 50 per cent. of water with gases leaving at 700° F. requires per barrel, with theoretical air supply, 120 pounds; with 50 per cent air excess, 128.7 pounds of coal. The amount of coal actually used is 150 to 160 pounds per barrel.

In these calculations the heat liberated by the chemical combination between the silica, alumina and lime has been neglected.

These figures show clearly the enormous waste of heat in the chimney gases. With the gases leaving at 1500° F. the available heat is reduced nearly 30 per cent, while if it left at 400° F. the loss would be only 7 per cent. The heat thus carried away is 413,918 B. T. U. per barrel, or each rotary kiln could produce from its waste heat 130 horsepower.

Prof. Joseph W. Richards * made a most thorough examination of a rotary kiln, burning a cement rock and limestone mixture in the dry state and using 110 pounds of West Virginia coal per barrel. The amount of clinker produced was 3,635 pounds per hour from 5,980 pounds of mixture, resulting in 200 pounds of flue dust or 3.35 per cent. of the weight of mixture charged. The temperature of the clinker as measured by the Chatelier pyrometer was 1200° C., 2192°F. The temperature of the waste gases in the chimney was 820° C.=1508° F. The sensible heat of the clinker was 290 calories per kilo. On analysis the composition of the waste gases was found to be:

	Per cent by volume.
Carbon dioxide.....	10.2
Oxygen.....	11.8
Carbon monoxide.....	0.2
Sulphur dioxide.....	} Not determined.
Water.....	
Nitrogen.....	

Atmospheric temperature 20° C. The heat balance of the kiln was now calculated to be:

Heat Generation.

1. Theoretical heating power of fuel.....	790,000
2. Heat of combination of ingredients forming clinker.....	142,819
	932,819

Heat Consumption.

Items of Distribution.	Calories.	Percentage of whole.
1. Heat in the hot clinker.....	100,050	10.7
2. Heat in chimney gases—		
a, In the excess of air admitted..... 336,000	.....	36.0
b, In the necessary products..... 340,000	676,000	36.1
3. Heat in flue dust.....	2,112	0.2
4. Loss by imperfect combustion.....	12,248	1.3
5. Evaporation of water charge.....	1,446	0.2
6. Expulsion of carbon dioxide from carbonates.....	21,628	2.3
7. Loss by radiation and conduction.....	119,335	12.8
Total....	932,819	100

*"Jour. Amer. Chemical Soc." Jany., 1904.

It was assumed that on forming silicates or aluminates 591 calories are given off per kilo of lime (according to Berthelot) and 827 calories per kilo of magnesia.

This work has brought out several interesting points. The heat of combination of the clinker is very large, making 18 per cent. of the heat developed by the coal. The heat in the clinker is a little more than one-tenth of the heat developed in the kiln.

The amount of heat carried out by the waste gases was found to be nearly $\frac{3}{4}$ of the total heat developed and 85 per cent. of the heating value of the fuel. If the excess of air admitted were reduced to 10 per cent. and the temperature of the gases reduced one-half by lengthening the kiln, the saving would amount to 60 per cent of the amount of fuel used. The amount of air admitted was 132 per cent. in excess over the theoretically required amount.

The maximum temperature of the flame was found to be, by calculation, 1000° C., that is, lower by 200° than the temperature of the clinker. This difference is due to the heat of combination of the clinker.

Temperature of Burning.—The clinker formation temperatures are given variously from 1200° to 1475° C., according to the kind of raw materials, the rapidity of burning, and the composition of the mixture. By burning slowly a much lower temperature can be employed, than by burning more rapidly. The average temperature in rotary kilns is probably close to 1300° C.

Pyrometers are not used in burning cement and in the nature of the case could not be well employed. They would be of little practical use, as the proper temperature, whatever it may be, is practically well fixed by the clinker itself, its appearance in the kiln, as well as by the feeding of definite quantities of coal determined by experience. An optical pyrometer might perhaps be used of the principle depending on measuring the intensity of light, by means of an instrument which is practically a photometer. Figure 53 illustrates such an apparatus consisting of a telescope with the necessary lenses and containing a standard incandescent lamp, *g*, in circuit with a battery, *e*, and resistance, *w*. The light admitted into the telescope is red, passing through the eye piece, *s*. On looking into a heated space the instrument is focused until the incandescent loop appears sharply as a black thread. The resistance, *w*, of the instrument is then so adjusted that the filament just disappears to the eye and when this is done the temperature may be read off from the scale attached to the instrument.

These instruments, such as the Holborn and Wanner pyrometers, have been brought to close and satisfactory standardization, but, after all, their use would not help the burner enough to pay for the trouble of

handling such a delicate instrument. For certain investigations, however, adjustment of coal feed or air inlet, endeavoring to fix the most favorable working conditions, these instruments in the hands of the technically trained men are valuable adjuncts. Other pyrometers, like the Chatelier, the Siemens and the air pyrometer, could hardly withstand the intense usage in the hot end of the rotary kiln due to the action of the volatilized alkali, ash, etc. The Chatelier pyrometer could be used in the upper end of the kiln for indicating the fluctuations in temperature

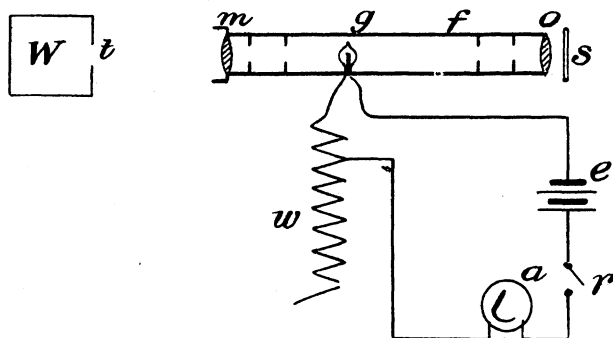


Fig. 53. Optical pyrometer, of the Wanner type.

and could be arranged to make automatic records, at the office. By means of an automatic switchboard one or two galvanometers could be made to serve an entire plant, though, of course, each kiln would require its own thermo couple. By using suitable clay shields the couple could be sufficiently protected for long usage. But, as has been said before, in the hands of untrained men all these instruments are of questionable value. For purposes of pyrometrical study the Chatelier pyrometer is preferred by the writer to any other.

REDUCTION OF HEAT LOSSES.

The *heat losses* of the rotary kiln may be reduced by the following changes:

1. Lengthening the kiln.
2. Utilizing the heat of the waste gases.
3. Utilizing the heat of the clinker.

Lengthening the Kiln.—1. This change, though greatly increasing the cost of the kiln, would bring about the most natural and greatest reduction in fuel consumption. This was fully realized by Edison when he constructed his kiln 150 feet in length. Owing to the great length of the tube the waste gases are compelled to leave it at a low temperature and hence part of the heat now wasted is rendered useful. By

proper jacketing the upper part of the kiln, the losses due to radiation could be reduced sufficiently so that the extra length of kiln would not give rise to excessive losses by radiation. In Germany rotary kilns are now in use, according to Michaelis, 90 feet long, which turn out, by the dry process, 300 barrels per day with a fuel consumption of from 60 to 75 pounds of coal per barrel, which is from 15 to 18 per cent. of the weight of the cement. The Edison kiln, 150 feet long, is 9 feet in diameter and is constructed of cast iron in place of steel and its fuel consumption probably approaches quite closely 50 pounds of coal per barrel. At the time the writer visited the Edison works, before they were in operation, a capacity of 700 barrels per day was expected from each kiln, based on extensive preliminary experiments.

From the theoretical standpoint, the lengthening of the kiln seems at present to be the most efficient and simplest method of reducing the losses of heat and probably will also be the direction in which the kiln is improved. All other expedients for utilizing the waste heat are secondary and are bound to result in a far smaller economy. If in a longer kiln, the gases are cooled to too low a temperature, mechanical draft must replace the stacks. For the wet process, however, the length of the kiln is limited by the dew point of the water-laden gases which are passing out from the kiln. Thus a 90 foot kiln having a capacity of 200 barrels per day, using a slurry containing 50 per cent. of water and consuming 120 pounds of coal per barrel, should not discharge the waste gases at a temperature below 85° C. If the temperature is lower, the kiln is too long. It has been assumed in this illustration that only the amount of air theoretically required for the combustion of the coal is introduced. Sometimes the statement is made that in burning by the wet process it is necessary to use excess of air, as the theoretical volume of air could not carry the great volume of steam evolved from the slurry. This evidently is not true; in fact, with the wet process, it is necessary to use as little air as possible in order to maintain the stack temperature high enough for sufficient draft. Taking it altogether, there is no serious complaint to make against the heat wasted in the rotary kiln fed with slurry. As long as the manufacturer starts with materials containing naturally much water and is compelled to evaporate this water, this might as well be done in the kiln as anywhere else, as long as it does not cause serious trouble there due to organic matter, forming of "rings," etc. Marl containing not more than 15 to 25 per cent of water should not be worked wet, but should be dried in the rotary dryer in the beginning of the process and then worked like any other dry mixture. Marl excessively high in organic matter likewise should be dried previous to grinding and burning. This is due to the fact that in the wet rotary,

the zone of high temperature is too short to allow of the complete combustion of the fine organic matter surrounded by the cement mixture.

The addition of water to typically dry materials like limestone and clay for the purpose of bringing about more intimate blending and more complete control of the mixture is not justified in principle.

Use of Waste Gases.—2. The idea of a long rotary kiln and the use of the waste heat has long been realized by inventors and engineers. The kiln proposed by De Navarro in 1891 employed the heat of the waste gases for preheating the air used in combustion, using also the heat of the cooling clinker. At Warners, N. Y., the waste gases were used for drying the clay and marl in a separate cylinder. The Stokes system of England does practically the same thing. Giron, in 1893, suggested the setting up of a boiler at the discharge end of the kiln, an idea which has recently again been taken up and carried out on a large scale by Prof. Carpenter of Cornell University.* A vertical water tube boiler was installed for each two kilns of a cement plant, the boiler having a heating surface of 3,000 square feet. Each boiler, however, was provided with furnaces for direct firing, if necessary. An elaborate and exhaustive boiler test developed the fact that two kilns generated 264 boiler horsepower. Another test showed that 254 horsepower were generated by the two kilns. During these tests the two kilns produced 8,018 pounds of clinker and consumed 1,888 pounds of coal per hour. The temperature, as measured by the Noel optical pyrometer, varied from 2350 to 2960° F. The gases left the boiler at 560° F., and the economizer at 350° F. During the test about 80 per cent. of the air entering the kiln was heated 480° F., restoring to the kilns 2,000,000, B. T. U. per hour, or 7 per cent. of the heat produced by the combustion of the coal. Some difficulty was experienced by the settling of kiln dust on the boiler tubes, about 4 pounds per hour, which was blown off every five hours. By the use of dust chambers as applied in blast furnace practice this slight difficulty should be entirely removed. In several other plants this difficulty is being overcome. The temperature in the burning zone of the kiln was about 2850° F.

Over one-half of the heat is discharged into the flue, of which 70 per cent. is utilized in steam, about one-sixth leaves with the clinker and about one-twelfth is lost by radiation.

Prof. Carpenter gives the following data which are very useful for purposes of reference:

**Cement*, Vol. V, No. 3.

Data Obtained in Test of Two Rotary Cement Kilns,
with Waste Heat Boilers.

Coal consumed per hour, lbs.	1,888
Specific heat of clinker.	0.2
Clinker produced per hour, (CaO=62%) lbs.	8,018
Weight calcium carbonate per hour, lbs.	8,875
Moisture in raw material.	3.1
Weight of carbon dioxide evolved per hour, lbs.	3,660
Weight of air supplied per pound of coal, at 44% excess, lbs.	16.1
Total weight of air supplied per hour, lbs.	32,397
Weight of air supplied by coal feeders per hour, lbs.	5,850
Total weight of gases discharged per hour, lbs.	37,749
Heat discharged per pound of gas 0.23(1800-100)B.T.U.	391
Area of outside of kiln, square feet.	1,213
Area of hood exposed, square feet.	76
Air entering kilns, average temperature, deg. F.	480
Air leaving kilns, average temperature, deg. F.	1,820
Air leaving boiler, average temperature, deg. F.	660
Air leaving economizer, average temperature, deg. F.	450
Temperature of kiln, lower third, deg. F.	2,350 to 2,960°
Temperature of kiln, upper part, deg. F.	2,960 to 1,800°

Heat Distribution.	B. T. U.	Per cent.
Total heat supplied, including heat of formation of silicates...	31,371,000	100.
Discharged from kiln to boiler.	14,859,859	47.8
Discharged with clinker (8,018 x 0.2 x 500).	4,409,540	14.2
Calcium carbonate decomposed (18,875 lbs., 765 per lb.)	6,789,375	22.2
126 lbs. sulphur trioxide liberated.	238,140	0.7
252 lbs. water evaporated.	303,200	0.9
Radiation and unaccounted for.	4,770,886	14.2
Radiation per sq. ft. of surface of kiln per hour.	1,700	....
Heat absorbed by boiler from kiln gases.	8,798,328	28.8
Heat absorbed by economizer.	1,178,998	3.8
Stack loss and boiler radiation.	4,882,533	15.6

To show the progress of the cement burning in the rotary kiln W. B. Newberry* examined the contents of a cooled, but not emptied, rotary kiln by taking samples at regular intervals of 48 inches throughout the kiln, starting with unburnt stone and finishing with the vitrified, perfect clinker within 48 inches of the lower end, 14 samples being taken. The kiln was fed with a cement rock limestone mixture and was 60 feet long,

**Cement and Engineering News*, 1902.

5½ feet in diameter and made one revolution in one minute and 30 seconds. Each sample was analyzed. The results are given in the accompanying table:

No.	Silica.	Alumina and iron.	Lime.	Magnesia.	Loss on ignition.	Remarks.
	Per cent	Per cent	Per cent	Per cent	Per cent	
1	13.7	6.00	42.12	1.97	35.30	} Bluish gray in color.
2	13.65	5.58	41.95	1.96	35.04	
3	14.38	5.70	41.63	1.88	34.84	
4	13.55	6.30	41.98	2.12	33.46	} Yellowish color.
5	14.33	6.27	44.05	1.65	32.76	
6	14.46	6.36	44.67	1.89	30.56	
7	14.90	6.55	46.19	2.30	28.38	} Yellow to brown, balls soft.
8	16.44	6.99	49.25	2.23	29.94	
9	17.03	7.80	53.04	2.30	18.44	
10	17.94	8.50	56.20	2.35	13.04	Bet. 10 and 11 mass hardens. Vitrified on outside.
11	18.60	9.04	59.00	2.70	8.82	
12	18.66	9.75	62.68	2.80	4.34	Brown, partially vitrified.
13	19.90	10.76	63.38	2.83	1.08	Decided difference, nearly black.
14	20.36	10.78	63.76	2.81	0.86	Black well burnt clinker

It is thus seen that the vitrification proper must take place very rapidly, being confined to the lower 12 feet of the kiln.

Utilizing the Heat of Clinker.—3. The heat from the cooling clinker is an item which deserves some attention. In a kiln of a capacity of 200 barrels per day, the clinker leaving at a temperature of 1220° C., if cooled down to 20° C. would represent an amount of heat equal to $(380 \times 0.2 \times 1200 \times 200 \div 2.2 = 8,304,000$ kg. calories per day, theoretically, which is equal to 1,186 kg. of coal with a calorific power of 7,000, or 2,609 pounds of this coal. Where coal is cheap, say \$1.00 per ton, as in Southeastern Ohio, where the cement company generally owns its own coal mines, the heat item is not an important factor and it is doubtful whether it would pay to install an expensive apparatus for saving any of this heat, especially since probably not more than 50 per cent. of it would be made useful. The extra cost of installment, the inconvenience of the

heaters, the extra cost for power would offset the gain. The case is different where coal is higher.

In most cement plants now the main question seems to be how to cool the clinker in the quickest manner without reference to saving the heat, and hence coolers are installed without any attempt to economy. Some of these coolers are merely iron towers with baffle plates, others are high iron cylinders which are kept filled with clinker which is discharged by gravity at the bottom, but in some cases the hot air is drawn out on top by the blowers, thus preheating part of the air. In most cases the clinker is simply heaped up in a large shed or in the open air in great piles from which the cool clinker is wheeled to conveyors taking it to the grinding machines.

There are several systems of regenerating clinker coolers, viz.:

1. Revolving cylinders.
2. Vertical cylinders.
3. Grate coolers.

Revolving Cylinders.—1. The first are cylinders arranged just beneath the rotary kiln, catching the clinker as it comes from the kiln, the connection between the kiln and cooler being made as air tight as possible. The air passes over the discharged clinker into the rotary kiln, being thus preheated. In this case it is advisable to inject the coal with air under as high a pressure as possible, so that as much as possible of the secondary preheated air be used. The inclination of the cooler may be the same as that of the kiln and it is, so to speak, a piece of the kiln broken off and lowered. Or the cooler "doubles up" beneath the rotary kiln, in which case its inclination is reversed, as in the apparatus patented by Navarro in 1891 (see figure 54).

One cooling cylinder may serve for two kilns. In operation this is the simplest and most easily operated cooler, but its heating efficiency is not very great. This can be increased, however, by putting in stirring devices, especially by projecting steps along the sides of the cylinder.

Vertical Cylinders.—2. Of the vertical clinker cooler we have as probably the best example, the Wentz cooler (see figure 55), in which air is blown through a vertical pipe perforated at intervals, from which the air is distributed through masses of clinker which gradually moves downward between alternately cup and bell-like iron baffle plates. The heated air is collected in a circular space surrounding the cylinder and is then drawn into the kiln. For successful operation the apparatus requires a higher air pressure than is usually carried by the blowers. One cooler can take care of at least two kilns.

Cooling Grates.—3. The grate cooler consists essentially of a cast iron grate or steps surrounded by a shell and a device for jarring the recep-

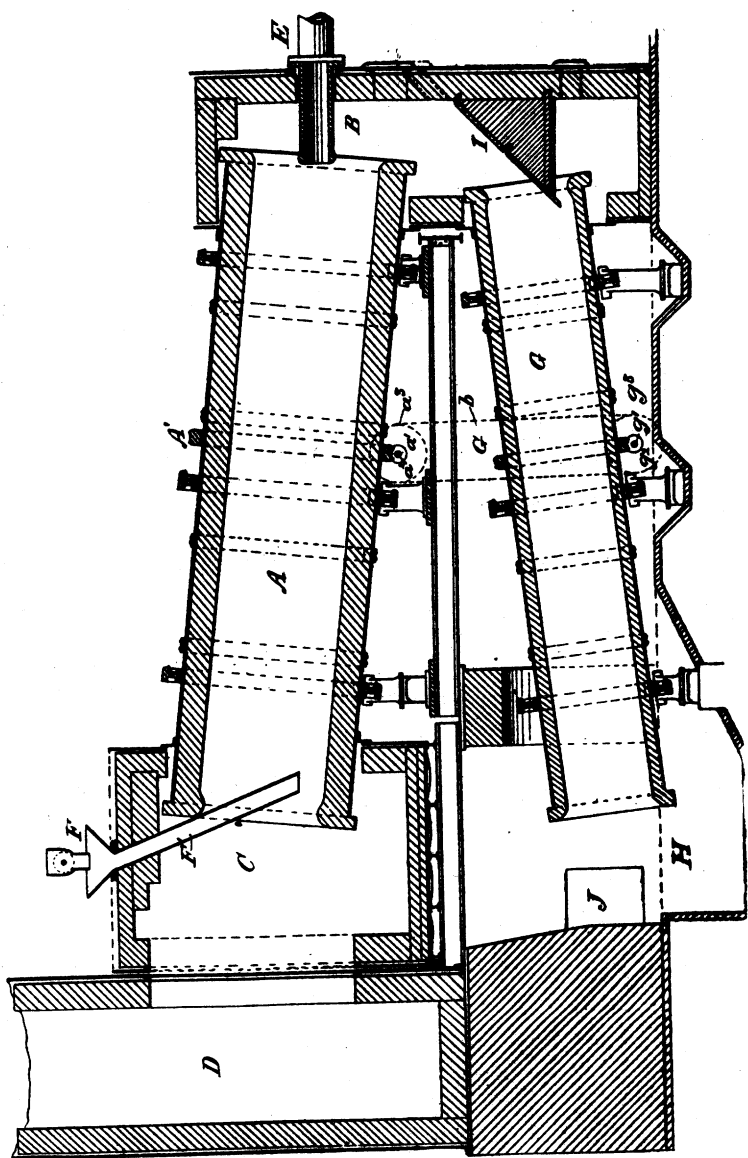


Fig 54. The Navarro rotary clinker cooler.

tacle. The clinker drops down the grate while air enters at the inlet (see figure 55). The heated air is exhausted by means of a fan, with water jacketed bearings. This apparatus was patented by Galschiot and seems to be a compact machine which does not occupy as much space as the inclined cylinder cooler and can be fed direct from the kiln, requiring no elevator. The clinker is removed by a screw conveyor.

It would be idle to attempt to save the heat from the clinker in a dry mixture plant while no attempt is made to get back some of the much greater amount of heat lost from the short kilns. What is needed most urgently at present is the close regulation of the air inlet into the ordinary kiln. That this can be done is affirmed by Mr. H. E. Brown, chemist of the Coldwater, Mich., Portland Cement Works, who stated to the writer that the analysis of the gases in his kilns showed an air admission of 97 per cent., using the wet method. It is necessary that strict control be kept of the firing conditions in our kilns by means of the Orsat or similar apparatus.

The Edison kiln 150 feet in length solves the entire problem of fuel consumption by allowing combustion to take place some distance from the lower end. The air is thus naturally preheated by the clinker and heat radiated from the zone of combustion while the waste gases are cooled down sufficiently by the long tube and are made to preheat the mixture.

REFRACTORY KILN LINING.

The question of the kiln lining is an important and much disputed one. In the majority of cases high grade fire brick are used in the combustion zone and lower grade brick in the cooler portions of the kiln. The whole question of refractoriness hinges, first, on the chemical composition of the material, and, secondly, on its physical characteristics, size of grain and porosity. Since the lining is in contact with a basic material, we would hardly expect that a silicious lining would prove satisfactory, although the sugar industry has used for lining its limekilns quartzitic rocks with fair success. It is generally assumed that the clay substance in its ideal composition is the best possible refractory, but we are at once confronted by the question of the kind of clay substance. We know in nature three distinct kinds of clay substances; the kaolin, forming a somewhat friable, slightly plastic mass which burns to a porous body; the horn-like, plastic ball-clay having almost the same composition, but containing small quantities of fluxes. This becomes dense even when burnt at low temperatures, but still has a high melting point; and lastly, hard non-plastic, flint clay. The kaolin is much more infusible than the ball-clay, showing a difference of perhaps 3 or 4 cones in actual melting point, but after all it does not stand up so well in the fire in contact with fluxing materials, slags or glass, simply because it is too porous in structure, allowing fused bodies to enter

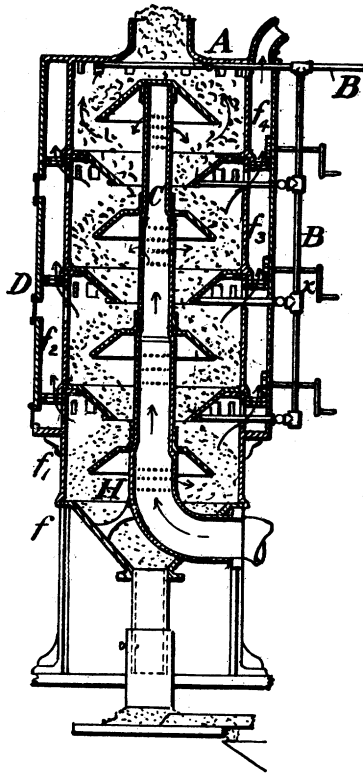


Fig. 55. The Wentz vertical clinker cooler.

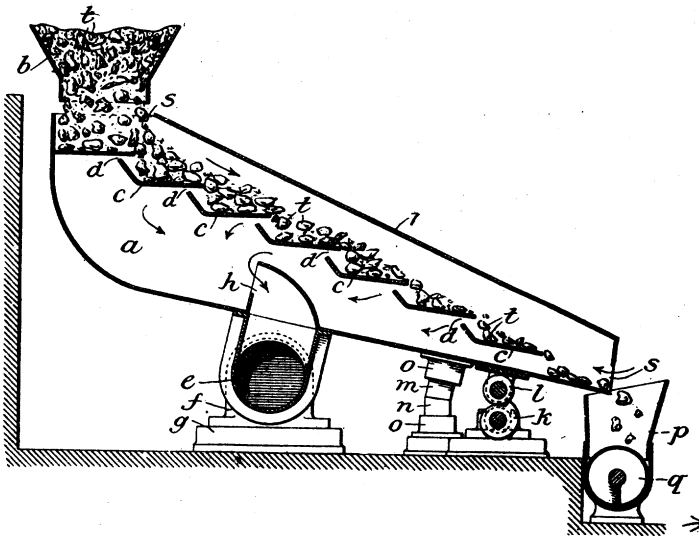
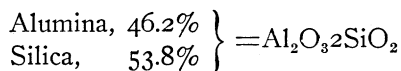


Fig. 56. The Galschloet grate cooler for cement clinker.

its pores. The third kind of clay, called flint clay, is a very hard infusible clay showing but slight plasticity, but great density. Its composition is almost identical with that of the kaolin. The latter must be ruled out owing to its porosity and we are to deal therefore with the plastic bonding clays and the flint clays. The latter, in themselves dense, would appear as the ideal refractory clay material, but there is this practical difficulty to be considered that, owing to their slight plasticity, they cannot be made into bricks by the ordinary processes. They require a certain amount of plastic clay to allow the bricks to be molded. The only method by which the amount of bond clay can be decreased is to press the bricks made from flint clay with a little plastic clay on a dry press. But this method, lacking the plastic bond developed by the use of water, results in a more or less porous brick. It might now be suggested that the flint clay be ground so coarse that its grains are difficultly attacked by the calcareous slag, but this again is not feasible, as then the bricks would become too friable and would not stand the mechanical abrasion they receive in the rotary kiln.

We are reduced, hence, to the use of a mixture of flint clay with as much plastic clay as will produce a body which is dense, but not brittle, and it is essential that the bricks are burnt as hard as possible in order that all the shrinkage may be taken out and they will not shrink in the rotary kiln. The addition of burnt clay grog to the brick mixture is not necessary unless certain shrinkage flaws show in the bricks. The sizing of the clay grains is not given the attention by fire clay men which the subject deserves. The body must not be made up of all coarse grains nor of all fine, but of a combination of both with a preponderance of the coarse grains. By coarse are meant grains between 10 and 20 mesh sieve, by fine those passing the 40 mesh.

In regard to the chemical composition it is important to note that Seger's results require for an ideal refractory clay the composition (when burnt):



Any increase in silica above this amount will reduce the refractoriness, down to 17 equivalents of silica to one of alumina; at this point the refractoriness again begins to rise, finally reaching the fusing point of silica. Seger also expresses the comparative refractoriness of a fire clay by the formula:

$$\text{Refractory quotient} = \frac{a}{(a+b) - b}$$

where a = the molecular ratio of the alumina to the fluxes (RO), that is, equivalents of alumina divided by equivalents of fluxes (RO) and b = the molecular ratio of the silica to the fluxes.

Seger, however, makes a special point of cautioning against the neglect of the importance of the physical condition and calls attention to the

fact that these are of great importance in governing the refractoriness of a clay. In considering the composition of a fire clay even the small amounts of fluxes and potash must not be neglected inasmuch as they exert an important softening action. A commercial kaolin of good quality (from Ledetz) was found to have the quotient 34.26 and did not fuse at the melting point of platinum, but appeared slightly translucent with the edges still sharp; a porcelain body of the composition:

	Per cents.
Clay substance.....	54.92
Feldspar.....	21.56
Quartz.....	23.52

having the quotient 10.29 fused to a glass and a brick clay, quotient 0.71 began to fuse at the melting point of cast iron.

The relative fusibilities of fire clays are hence fairly established by this ratio. Seger's, Bischof's and other refractory quotients are based on the following general laws of fusibility of fire clays derived largely from the work of Richter:

1. The refractoriness of clays is dependent upon the proportion of flux to silica and alumina.
 2. The fluxing action of the various bases is proportional to their molecular weights. Thus 40 parts of magnesia exert the same fluxing action as 56 parts of lime or 62 parts of soda.
 3. The fluxes are more active in a silicious than in an aluminous clay.
 4. The most essential factor is the ratio of silica to alumina; the more aluminous the clays are the more refractory they will be.
 5. If alumina is present in small amount it plays the role of a flux.
- The following analyses represent fire clays which have given good satisfaction in cement kilns:

No.	Silica.	Alumina.	Ferrie Oxide.	Titanium Oxide.	Lime.	Magnesia.	Potash.	Soda.	Chemical Water.
1	45.65	39.96	0.14		0.21	0.12	0.18		13.75
2	46.20	39.35	0.10		0.15	0.09	0.22		14.00
3	44.95	37.75	2.70		0.30	0.21	0.98		13.05
4	45.42	36.80	3.33		0.87	0.45			12.65

It will be noted that these analyses represent raw clays.

In order to study the effect of lime on sand and clay Cramer carried out a series of experiments by mixing marble with sand and

with kaolin and determining their melting points. He also replaced the marble by Portland cement. His results are found in the following table:

Number.	Proportion for 100 parts by weight of marble.	Formula.	Melting point in Seger cones.	Percentage composition.			Melting point on replacing the marble by cement.
				CaO	Al ₂ O ₃	SiO ₂	
1	120 parts sand	CaO2SiO ₂	below 26	31.8	.....	68.2	much below 26
2		Al ₂ O ₃ 2SiO ₂	35	.....	46.2	53.8	
3	180 parts sand	CaO3SiO ₂	29-30	23.7	.....	76.3	below 26
4		Al ₂ O ₃ 3SiO ₂	33	.....	36.4	63.6	
5	240 parts sand	CaO4SiO ₂	32	18.9	.....	81.1	29
6		Al ₂ O ₃ 4SiO ₂	32	.....	30.0	70.0	
7	518 parts kaolin	CaO2Al ₂ O ₃ 4SiO ₂	much below 26	11.2	41.0	47.8	below 26
8	480 parts sand	CaO8SiO ₂	32-33	10.4	.....	89.6	31
9	Al ₂ O ₃	Al ₂ O ₃ 8SiO ₂	29	.....	17.6	82.4	
10	1,036 parts kaolin	CaO4Al ₂ O ₃ 8SiO ₂	30-31	5.9	43.5	50.6	30

These experiments indicate that the fusing effect of excessive lime on sand is much less than has been realized so far. A mixture of 76.3 per cent. of silica and 23.7 per cent. calcium oxide still requires a temperature of cone 29 for fusion and the CaO4SiO₂ mixture, 18.9 per cent. calcium oxide and 81.1 per cent. of silica has a melting point of cone 32. At the same time 5.6 per cent. of calcium oxide suffices to lower a clay melting at cone 35 to cone 26. This seems to explain why lime burners have used quartzite for lining their kilns. However, the case is evidently different with cement, which contains beside lime and silica, alumina, iron and alkalies.

Fire bricks are tested with regard to their use in cement kilns not so much for refractoriness as for physical structure, though, of course, it is understood that a clay should never fuse or soften below cone 30. Some manufacturers test the brick by heating them to redness and dropping them into water. If the bricks do not crack they are considered satisfactory. Really comparative tests have as yet not been worked out. The pyrometric tests are made in a Deville or electric furnace.

Basic Linings.—Besides clay bricks, basic linings have been proposed. These, if they could be realized, would be the most suitable materials.

Magnesite bricks have been tried, but owing to their high price, great brittleness and high heat conducting power have not been successful.

Beauxite bricks or additions of beauxite to clay have also been disappointing as far as the writer has been able to learn.

Cement clinker linings, consisting of crushed and screened cement clinker and a little sand, have been quite successful, according to the reports of two cement mills. These linings are put in like concrete, and if they should prove satisfactory in every respect would afford an easy solution of a troublesome problem. Further data, however, are necessary before a final opinion can be given.

Kiln Improvements.—The rotary kiln is experiencing constant changes in various respects, of which a few will be quoted. Edison proposes the use of two jets of coal dust (see figure 57). Michaelis, Jr., obtained a patent on projections arranged around the kiln wall which are to retard the movement of the material downward, but which in the opinion of the writer are liable to give a great deal of trouble in operation. Another inventor proposes the use of a water jacketed kiln lining in the hottest zone analogous to the blast furnace lining. Lessing provides the kiln with a ribbed lining through which small jets of air are forced under pressure, and a good many other modifications might be cited.

Shaft Kiln.—The vertical shaft kiln used so extensively in Europe has no place under American conditions owing to its greater cost of operation due to the extra labor required, the cost of briquetting and the irregularity in output and quality of clinker. Its intrinsic fuel consumption is, of course, considerably less than that of the rotary kiln, being about 61 pounds of coal per barrel under favorable conditions. If used at all the system adopted should include the dry pressing of the raw cement bricks and burning the kiln with forced draft so as to increase the capacity. Figure 58 represents the Dietzsch shaft kiln operated continuously.

Fusing Portland Cement.—Occasionally the idea of doing away with all intermediate and fine raw grinding machines by fusing the cement to a liquid mass and grinding the resulting cooled slag crops up. This certainly is a fascinating idea and appeals to the theoretically inclined mind quite strongly. To make Portland cement by charging limestone and clay into a blast furnace and running out the liquid slag certainly seems a simple process. Jex in 1900 suggested that the lime in the Portland cement composition be lowered, as fused cement would require less lime than vitrified cement. Thus he suggests among others a cement of the following composition:

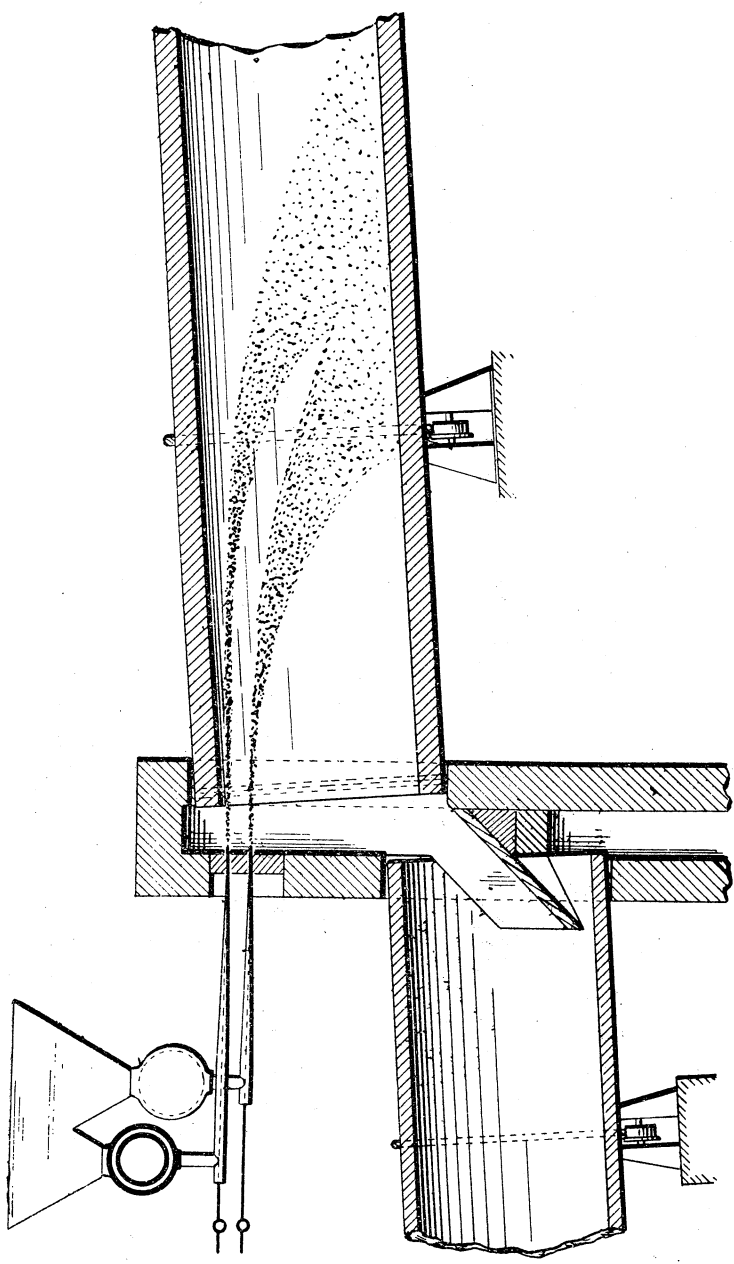


Fig. 57. The double-jet dust-coal firing system, proposed by Edison.

	Per cents.
Silica.....	32.55
Alumina.....	1.93
Ferric oxide.....	1.10
Calcium oxide.....	62.49
Magnesium oxide.....	1.93

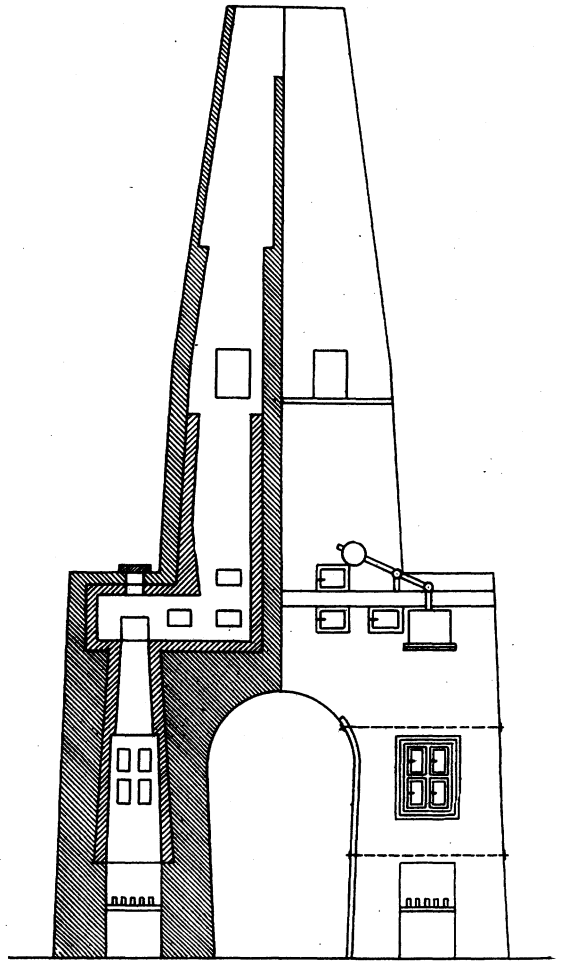


Fig. 58. The Dietzsch vertical cement kiln.

According to him the cement burnt in a shaft kiln requires 80,000 large calories per 220 pounds, while by fusion the same amount of cement could be produced with 200,000 calories, from which the heat energy corresponding to the crushing and grinding must be deducted.

Coal Grinding.—It will be found necessary quite frequently, in fact nearly always, to dry the coal in a rotary dryer before pulverizing it.

The coal is usually received in nut size. The dryer is usually about 30 feet long by 5 feet in diameter. The grinding is done in two stages. For the first grinding there may be employed:

1. Rolls.
2. Disintegrators.
3. Ball-mills.

The disintegrator appears to be the most efficient machine for this purpose. The fine grinding may be accomplished in:

1. An æro pulverizer.
2. A Griffin mill.
3. A tube mill

The æro pulverizer is a disintegrator in two or three stages, that is, with two or three revolving cages or hammers varying in size and revolving with great rapidity. The fine coal is blown up a tube and passes through a chamber in which the coarse particles are separated and drop, being returned to the pulverizer by gravity. In size the machine is much smaller than the clay or limestone disintegrators. The writer was informed by those using this machine that it is very efficient, but has a reputation, justified or not, of being somewhat dangerous owing to the great velocity of the rotating parts, and is said to be liable to coal dust explosions. This last statement, the writer has been unable to verify. This system is illustrated in Fig. 59 on page 318.

THE GRINDING OF THE CLINKER.

From the kilns, the hot clinker drops either into iron cars, a horizontal pan conveyor or a cylinder cooler. The conveyor collects the clinker from all the kilns and delivers it to a chain elevator, which again conveys it to a horizontal conveyor. The latter takes it to the clinker pile. Where vertical cylinder coolers are used, the clinker from two kilns is delivered to one cooler. In some mills the clinker is quenched by spraying water on it or the pan conveyor may be arranged to run in water so that the clinker is cooled without becoming wet. The effect of the spraying is beneficial so far as the quality of the clinker is concerned, inasmuch as clinker with any tendency to dust is improved and also it becomes more friable, easier to grind. On the other hand the heat of the clinker is thus to a large extent dissipated and it would be hardly worth while to make an attempt to save it.

The cooled clinker is now ready to be ground. At this stage the raw gypsum is added either by rough weighing or by guess, so many shovels to a barrow load of clinker. The amount usually added is 2 per cent., and the cost of the plaster is hence a considerable item in the manufacture, its cost being from 7 to 10 dollars per ton. This is a powerful argument in favor of cement compositions requiring no gypsum or but a small amount.

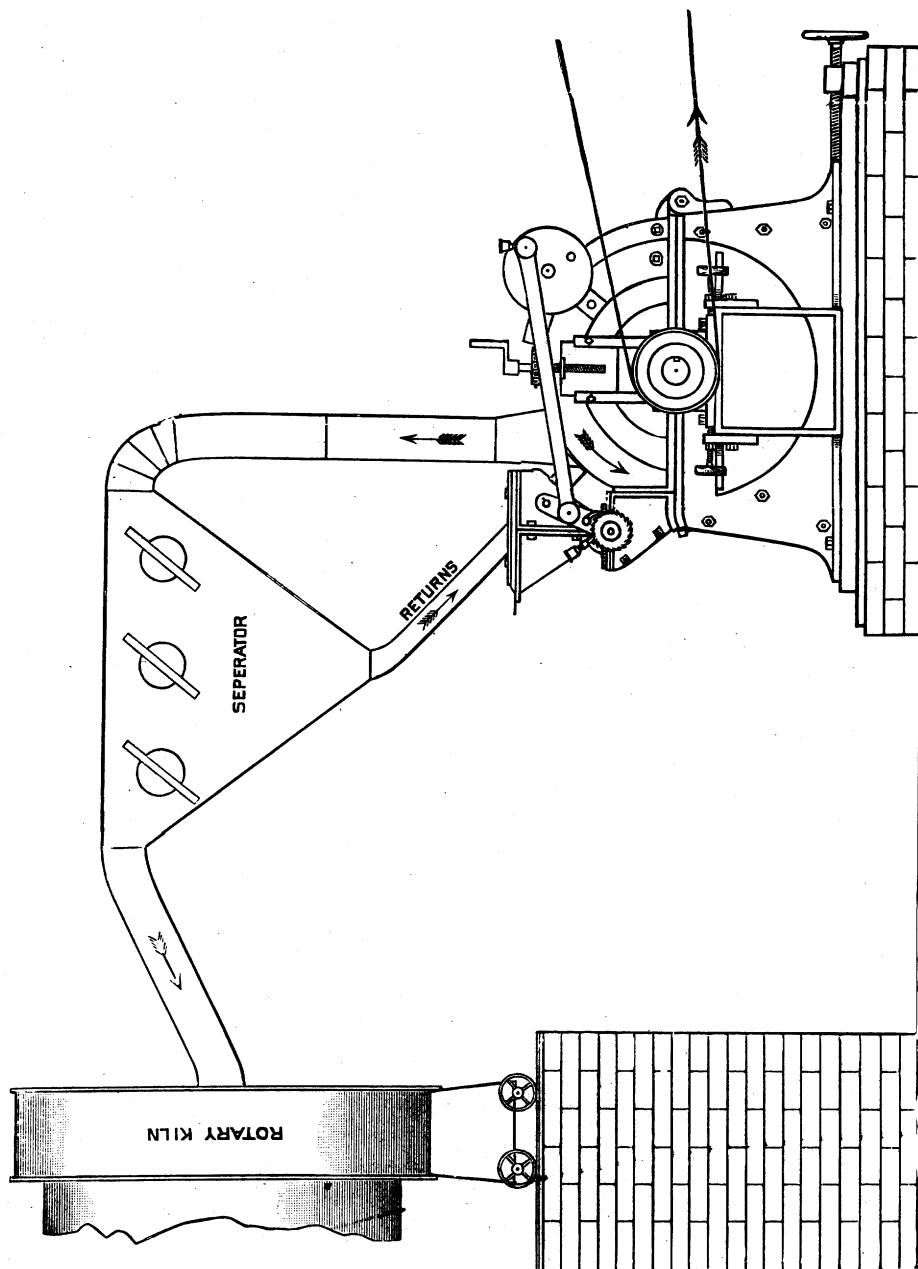


Fig. 59. The system of the aero pulverizer, applied to coal grinding, and direct feeding of cement kiln.

In grinding the clinker we require again intermediate and fine grinders. The intermediate grinder may be:

1. Rolls.
2. Kent mill.
3. Disintegrator.
4. Ball-mill.

and the fine grinders:

1. Griffin mill.
2. Tube mill.

What has been said in regard to the relative mechanical efficiencies under the head of raw grinding holds true also here and the economic values of these machines range probably in the order in which they are given. One source of loss in efficiency is the fact that the fine material produced in the intermediate grinding machines passes on to the fine grinding machine and hence lessens its efficiency to this extent. This seems to the writer one defect in the usual American mechanical outfit, but can be easily remedied by the insertion of a wind separator, of which there are many makes on the market depending on centrifugal action or on simple air blasting (see figure 59). In fact these machines are probably destined to revolutionize the present clinker grinding system by doing away with the fine grinding machine entirely. This could be done by selecting a machine which furnishes a high percentage of fine material, like the Kent or ball-mill, separating out the finest by means of the wind separator and returning the coarse material to the grinding machine. This would undoubtedly cheapen the process considerably.

The clinker grinding machines according to the present system might be arranged as follows:

Rolls or Kent mill, or disintegrator, or ball-mill.
Dust separator.
Griffin or tube mill.

The rolls, with two passes, have the greatest efficiency, showing probably the least cost of power. Their capacity is about 30 tons per hour with a consumption of approximately 100 horsepower.

The Kent mill, requiring 25 to 30 horsepower, has probably an output of from 22 to 28 barrels per hour, preparing the clinker for the tube mill, depending on the hardness of the clinker.

The disintegrator has been claimed by some manufacturers to be not very efficient for clinker grinding owing to the heavy expense for repairs, due to the direct impact of the rapidly revolving bars, which probably is true. The repairs for this machine in clinker grinding are considerably greater than in raw grinding, where it has proven very successful in every respect in a number of instances.

The ball-mill has been discussed sufficiently under the topic of raw grinding and was quoted as having a capacity of 12 to 16 barrels per hour through the 20 mesh sieve, requiring 30 to 40 horsepower and 18 to 24 barrels with 40 to 50 horsepower. It is not an economical machine as an intermediate grinder.

As to the comparison between the Griffin and the tube mill, it must be stated that the Griffin mill is the more economical of the two in spite of its heavy repairs. Its tendency to separate particles of different specific gravity cannot be made a point of criticism here inasmuch as the material is homogeneous in character. The capacity of a Griffin mill is from 8 to 10 barrels per hour, requiring 25 to 30 horsepower.

The capacity of the tube mill, 22 feet by 5 feet, is 14 to 20 barrels per hour, requiring 70 to 75 horsepower to operate and 125 horsepower momentarily in starting.

Fineness of Grinding.—It has been claimed repeatedly that the product of the tube mill is far higher in finest material than that of any other machine, and hence cement ground by this machine is supposed to be higher in quality owing to the large amount of cement dust present. The writer investigated this point by collecting himself samples of cement ground by several types of machines and having mechanical analyses made, using for separating the fine particles alcohol re-distilled over caustic lime. The results of these analyses are shown in the following table on page 321.

These results, of course, cannot be used to condemn any machine, as other factors enter into the consideration of grinding, so that the very attempt to draw general conclusions in regard to the quality of the grinding would be absurd. However, in comparing the figures of column 10 it is seen that they are quite in favor of the Griffin mill and show that in practice this type of machine is more than the equal of the tube mill. It is also observed that the finer cements show a higher tensile strength with 1 : 3 briquettes, just as is to be expected, for the sand test is to some extent a test for fineness of grinding. There is perhaps a tendency in practice to overcrowd the tube mills or to feed them irregularly. This may account for the poorer showing of the tube mill.

These experiments, in addition, show that the usual sieve analysis is not a satisfactory and accurate means of measuring the real fineness of cement, since the 100 mesh sieve commonly employed tells practically nothing about the amount of cement dust present.

In the method proposing to use only an intermediate grinding machine, together with an air or centrifugal separator, it would probably be best to use the Kent mill or rolls. The latter have proven quite efficient at the works of the Edison Company.

Number.	Grinding machine used.	Residue on 80 mesh sieve.	Residue on 120 mesh.	Residue on 200 mesh.	Grains average diameter 0.0020 in.	Grains average diameter 0.00072 in.	Grains average diameter 0.0003 in.	Grains below last size.	Portion finer than 200 mesh.	Tensile strength 1 cement 3 sand pounds per sq. in. after 28 days.
1	Tube mill	7.07	14.56	4.45	22.68	19.29	7.36	24.69	74.02	296
2	Tube mill	9.01	15.35	5.09	21.50	20.53	7.06	21.52	70.61	318
3	Tube mill	12.12	15.05	7.61	21.11	16.85	5.91	21.37	65.24	303
4	Tube mill	14.11	14.57	7.82	22.43	13.95	7.81	19.32	63.51	208
5	Tube mill	3.84	17.64	5.10	25.27	17.56	10.16	20.42	73.41	297
6	Griffin mill	3.06	15.41	8.24	28.56	16.48	12.74	15.51	73.29	350
7	Griffin mill	9.43	16.91	6.37	25.52	12.18	9.20	18.49	65.39	313
8	Griffin mill	5.00	15.42	14.52	27.30	19.10	9.22	14.88	70.50	285
9	Griffin mill	4.40	11.35	5.13	23.79	21.30	10.01	24.01	79.11	346
10	Griffin mill	4.18	13.30	5.07	22.63	14.64	12.31	28.79	78.37	314
11	German cement	3.88	15.84	7.63	27.63	17.83	13.30	13.89	72.65	281
12*	Mill stones	7.36	9.93	3.53	16.42	13.98	14.74	34.04	79.18	317†
13*	Mill stones	12.50	11.59	4.29	16.52	21.95	17.42	15.76	71.65	299†
14*	Tube mill	10.53	12.85	8.50	11.39	22.15	20.72	13.85	68.11	265†

*Numbers 12, 13 and 14 are Natural Cements. †1 Cement 1 sand was used in these briquettes. The tensile strengths given are the averages of five briquettes.

In regard to the capacities of the different machines Professor Carpenter gives the following summary:

Machine.	Capacity in tons per hour.	Power used.
Rock crushers.....	.....	1.1 horsepower per ton.
Rolls.....	.....	1.5 horsepower per ton.
Griffin mill, rock.....	1.5 to 3	27 to 33 horse power.
Griffin mill, clinker.....	0.8 to 1.5	27 to 35 horsepower.
Griffin mill, coal.....	1.5 to 2.0	16 to 24 horsepower.
Ball mills, on rock to 20 mesh.	2 to 4	20 to 30 horsepower.
Tube mill, producing dust....	2 to 4	70 to 80 horsepower.

Dust Collectors.—One class of machine found lacking in American cement mills is the dust collector of European works. Every effort is made there, made compulsory by law, to separate out the dust floating in the air as much as possible, and hence regular plants of good size are installed for this purpose. The dust being decidedly injurious to health, it should be the aim of every manufacturer to install such dust collecting plants, especially since their cost is not great and in part is repaid by the fine cement dust collected. The writer has visited plants in which the enormous amount of dust floating in the air was a positive menace to health. By the exercise of a little engineering skill this state of affairs could be remedied without difficulty, just as has been done in other industries. There are a great many appliances on the market for collecting dust by exhausting air from the working space, passing it repeatedly through settling chambers and catching the remaining particles by means of cloth filters.

MECHANICAL EQUIPMENT.

Dry Process.—We can now summarize the mechanical equipment of dry grinding cement plants as follows:

Limestone.

1. Rock crusher.
2. Intermediate grinder,
(rolls, disintegrator or
Kent mill).
3. Limestone Bins.

Clay or Shale.

1. Coarse grinder (rolls or
rock crusher, if hard.)
2. Rotary dryer.
3. Disintegrator.
4. Clay bins.

The materials, each in separate bins, are now discharged from the bins by gravity on to horizontal belt conveyors and fed into two smaller

bins, side by side, one for the limestone and one for the clay. Here they are weighed out by means of a double scale and dumped into a large mixer of the granulator type consisting of a large box, V-shaped, in cross section, in which, at the bottom, a screw conveyor shaft revolves, carrying also larger mixing blades. The shaft is to be very heavy. The bottom of the mixer slopes from the discharge end down to the inlet end so that the space at the inlet end is far greater than at the discharge end and can be made to hold several tons of material. Being about 16 feet long, the mixer discharges the raw stock in a steady stream into a screw conveyor, not less than 8 feet long, which feeds another smaller storage bin, from which the ball-mills are supplied. This bin thus brings about additional mixing and blending. Since the material has been through an intermediate grinder before, the ball-mill has a greater capacity and its principal function is to produce further mixing and blending together with additional grinding. Two of these mills should supply four tube mills without any difficulty. Thus, starting from the separate limestone and clay bins, we have the following equipment:

- a double bin,
- b scales,
- c mixer,
- d screw conveyor,
- e feeding bin,
- f ball mill,
- g tube mills,
- h storage bin over kilns,
- i rotary kilns.
- j clinker cooler,
- k Kent mill,
- l wind separator,
- m Griffin mill,
- n to storage bin.

The principal advantage claimed for this arrangement is the fact that the mixture is under the best control possible in a dry plant, since storage bins are provided for, which permit of analyzing and checking the limestone and clay in bins which are independent units. Until analyzed and approved by the chemist, the bin is not to be emptied. By calculating the mixture for one limestone bin and one clay bin, which is considerably smaller, these two bins are emptied and their contents weighed out in the proportion calculated. By supplying each bin with an automatic sampling device on top its exact average composition may be obtained. Of course it is important that the bins be not too large. Such an arrangement would lessen one of the greatest objections to the dry process in which, as it is well known, errors in the com-

position cannot now be corrected in the average plants of today, but must be allowed to pass on with the certainty of producing an inferior product.

The bins, of whatever kind, should be supplied with bottoms permitting of emptying by gravity. This applies to the cement bins as well as the raw stock bins.

In the accompanying diagram this equipment is outlined. It will be noted that the draft for the kiln is provided by exhaust fans, the waste heat being passed through boilers and a feed water heater. The heat of the cooling clinker is supposed to be used for preheating the air introduced for the combustion of the coal. If the clay is very coarse, or if sandstone is added to the mixture, it might be necessary to insert a tube mill between the clay disintegrator and the clay bins, in order to insure sufficient grinding or, if preferred, another tube-mill might be added to the fine grinding equipment and the feed reduced for each mill, so that more time is given for the grinding. A flue is also indicated through which some of the waste gases might be exhausted and conducted through the dryer, so that the fuel item for the drying is eliminated. The coal should be ground in a disintegrator and Griffin mills. This diagram, of course, is only intended as a suggestion, for covering the ordinary difficulties which arise. In any individual case, modifications would be likely to be needed to suit the special peculiarities of the stock and fuel.

Wet Process.—Here the machinery required is much simpler owing to the soft and fine grained character of the materials.

Marl.

1. Blunger or wet pan with perforated bottom.
2. Tank, kept agitated.

Clay.

1. Dryer.
2. Disintegrator.
3. Bin.

- a. Mixer.
- b. Tube-mills.
- c. Storage and correction tanks.
- d. Kilns.
- e. Clinker cooler.
- f. Kent mill.
- g. Wind separator.
- h. Griffin mill.

Storing Cement.—The stock house should be large enough to hold at least one month's run of cement. It is preferably built of concrete and divided into a number of bins. By testing the cement in each bin by the usual physical tests, taking care to sample the bin thoroughly, the

*Suggestive Diagram of a Portland Cement Plant
using a Limestone-Clay Mixture*

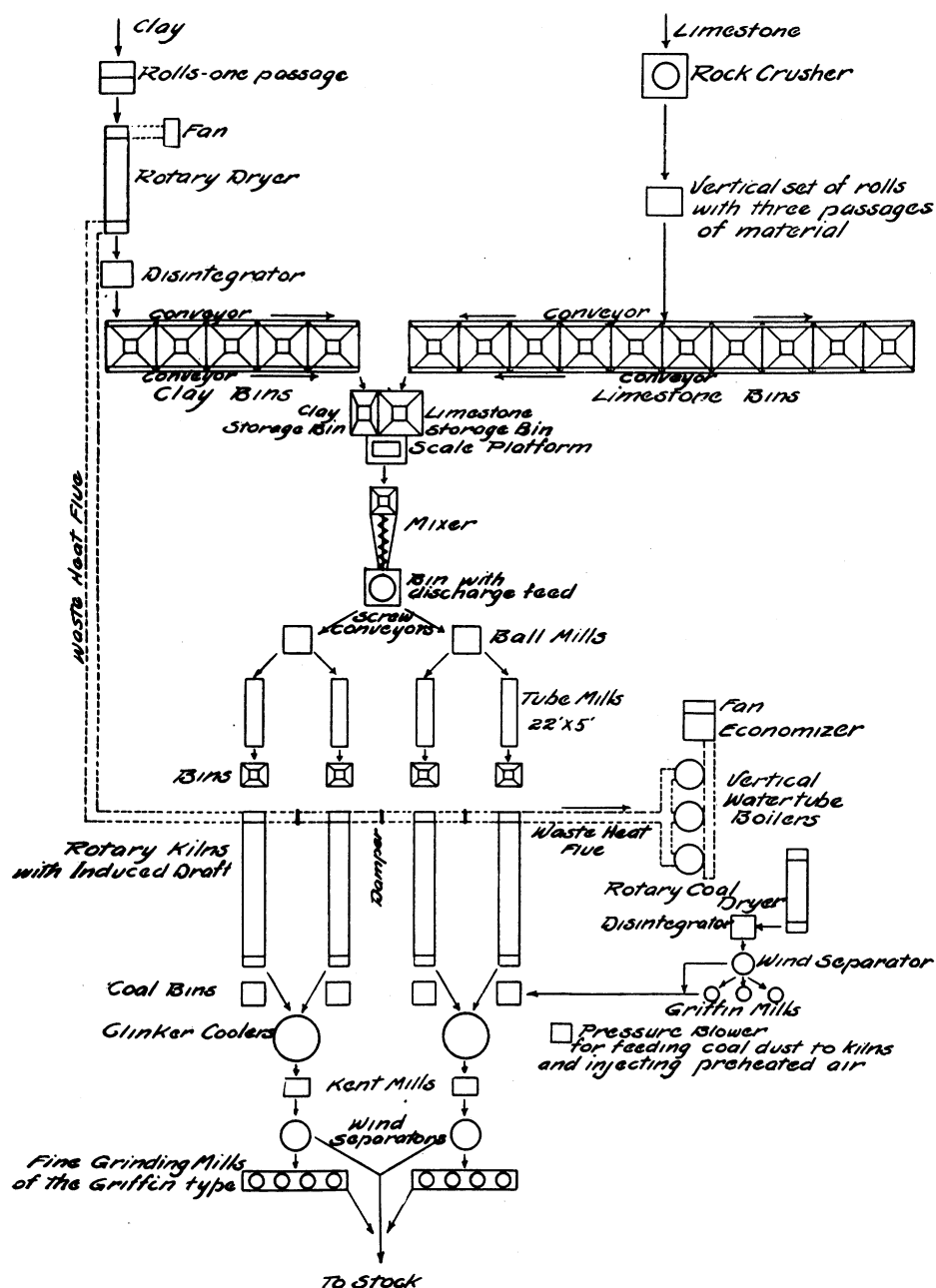


Fig. 60. General ground plan of a Portland cement works, showing sequence of mechanical treatment.

chemist allows the cement in such a bin to be shipped, keeping a record of the tests made. Theoretically, of course, the cement should be kept stored in thin layers to which the air has ready access, but in practice this is difficult to carry out. The bins should have a sloped bottom so that the cement can be discharged by gravity by simply lifting a slide. The packing is usually done at one end of the stock house. In regard to the use of packing machines opinions seem to differ, some advocate them, others think hand packing is just as cheap. Evidently the amount saved, by using machines, if there is any saving, is quite small. Sacks are used mostly at present in place of the barrels which were employed almost exclusively a few years ago.

The net weight of cement in barrels varies somewhat according to whether the cement is packed or is loose. S. E. Thompson found the net weights of cement per barrel to vary from 370.07 to 387.0 pounds. A cubic foot of various Portland cements, packed and loose, was weighed and found to weigh as follows:

	Packed pounds.	Loose pounds.
Giant.....	113.81	91.38
Alsen.....	118.45	89.20
Taylors.....	122.75	94.24
Dyckerhoff.....	123.16	93.18
Atlas.....	117.54	100.49
Aalborg.....	115.71	91.40

The barrels weigh from 21 to 25 pounds. Each barrel is supposed to contain 380 pounds of cement, each sack 95 pounds.

Power Required in Cement Works.—A good basis for estimating the power required is afforded by the figures, already quoted, in part, which represent the power required at the cement works of Wm. Krause and Sons, Martin's Creek, Pa., as determined by actual measurement from the input and output of the electric motors used. The friction load of the plant, main shaft 6 inches in diameter and 240 feet long, is 55 horsepower. Power to drive 4 ball-mills is 155 H. P. or per mill 39 H. P. Five tube-mills use 333 H. P. or 66.6 H. P. per mill.

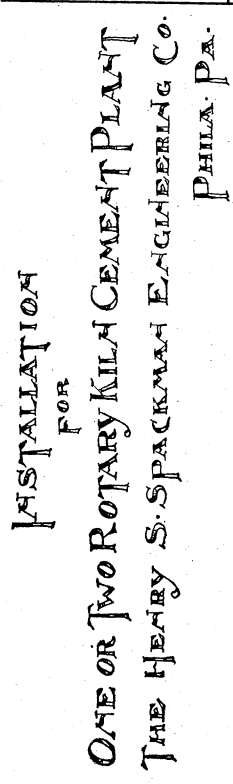
Each kiln, one revolution per minute, uses 3.7 H. P. A 30 foot belt conveyor for stone, 1.2 H. P.

A stone crusher of a capacity of 25 tons per hour, with its bucket conveyor, 32.6 H. P., maximum load.

Stock house, screw conveyors 450 feet long, 2 barrel conveyors, packers and shafting, 19.5 H. P.

Each figure represents the output of the motor for the purpose designated.

A convenient rule for estimating the power required in cement mills is: One H. P. for each barrel produced per day if marl is used and 1.5 H. P. per barrel per day if rock is worked.



In regard to the power consumed in operating elevators, screw conveyors and belt conveyors, Carpenter gives the following rules:

W=weight of material moved per minute.

l=distance moved per minute, in feet.

Elevators:

$$\text{H.P.} = \frac{Wl}{33000} \times \frac{5}{8} = \frac{5Wl}{264000}$$

Screw conveyors:

$$\text{H.P.} = \frac{Wl}{33000} \times \frac{4}{10} = \frac{4Wl}{330000}$$

Belt conveyor:

$$\text{H.P.} = \frac{Wl}{33000} \times \frac{1}{8} = \frac{Wl}{26400}$$

Power Plant.—As the price of coal is constantly rising and the cost of the fuel is the heaviest item in the cost of manufacturing cement, manufacturers should give special attention to all coal saving prime motors and devices. The modern tendencies toward lowering the cost of power move in the following directions:

1. Compound condensing engines, using superheated steam.
2. Steam turbine and electric distribution of power.
3. Gas engines and electric distribution of power.

The most radical decrease in cost is offered by the use of gas engines using generator gas. With the improvements of the modern gas engine the use of this type of motor is rapidly becoming a practical proposition and means a reduction in the cost of power of from 50 to 75 per cent., compared with the best and the average steam plants. One cement plant operating with gas engines using natural gas, the Iola Portland Cement Co., Kansas, is reported a perfect success.

Transmission of Power.—It is now generally realized that long and heavy shafting is a source of loss of power and electric transmission has been rapidly adopted in many plants. This affords an ideal way of distributing power even though it is not cheaper in actual operation than shaft transmission. However, unless carefully protected the ordinary motor is bound to suffer through the dust and dirt always present in a cement mill. This difficulty is overcome by the induction motors which are now built practically dust proof.

Where large powers are transmitted by shafts, rope transmission should be used.

The Cost of Making Portland Cement.—It is not the intention of the writer to quote estimates of cost given him by managers and superintendents of plants, for the reason that no figures which could be given

would have any broad utility, owing to the greatly varying conditions under which different plants must always operate. Neither is it good policy, in the writer's opinion, to publish broadcast ideal figures, which might attract capitalists and lead them to expect extraordinary profits, thus causing overproduction and ruinous competition, such as has been experienced in some cement districts. The profits of the cement business are close and sound management is required. A works not over capitalized and not handicapped by unsuitable conditions, high cost of raw material or of fuel or poor shipping facilities, can expect a fair and constant profit, but soon

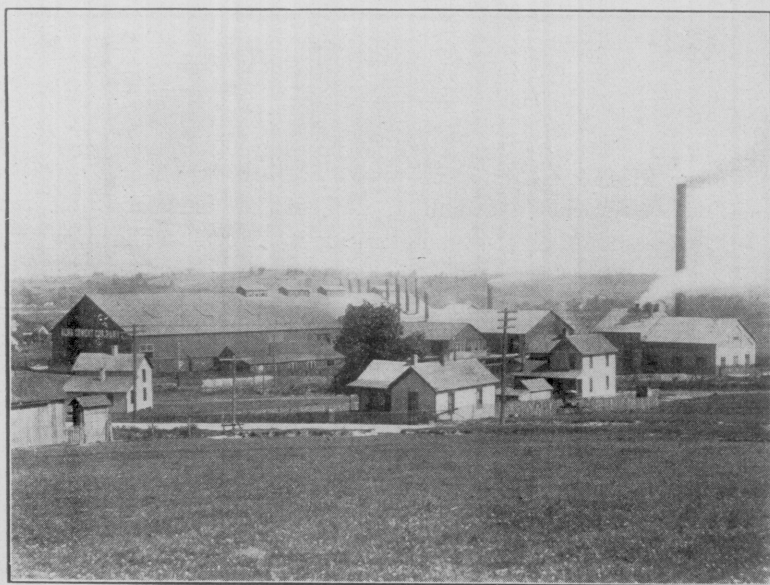


Fig. 61. View of the Alma Portland cement plant, at Wellston, Ohio.

it will be a question of the survival of the fittest, just as has been experienced in Germany and other countries. The growth of the American cement industry has been enormous, and in spite of the growing number of uses to which cement is put, the supply will soon be equal to the demand. It is to be hoped that the import of cement to the United States will soon be a thing of the past and that our country will acquire its share of the export trade in our natural markets, South America and the American possessions in the east, as well as in the other markets of the world.

First Cost.—In order to afford some basis of comparison in regard to the first cost of a cement plant the following rough estimates are quoted. Machinery for a two rotary plant, working limestone and clay, about 350 barrels per day of 24 hours.

Number of machines.	H. P.	Approximate Cost of		
		Machinery.	Foundation and Supports.	Erection or Installation.
Raw Material Machinery.				
1 Stone crusher, No. 5.....	50	\$ 1,700	\$ 100	\$ 50
1 Clay disintegrator.....	25	750	50	25
2 Driers.....	20	3,000	600	150
1 Ball mill, 5' x 10'.....	50	2,800	125	75
1 Tube mill, 5' x 22'.....	50	2,700	125	100
	205	\$10,950	\$1,000	\$ 400
Calcining Machinery.				
2 Rotary kilns, 6' x 60'.....	15	6,200	400	300
Bricks for lining and setting kilns.....		800		250
1 hot clinker elevator.....	5	400	40	50
1 Clinker cooler.....	5	1,300	75	50
	25	\$ 8,700	\$ 515	\$ 650
Clinker Grinding Machinery.				
1 Ball mill, 5' x 10'.....	50	2,800	125	75
1 Tube mill, 5' x 22'.....	60	2,700	125	100
	110	\$ 5,500	\$ 250	\$ 175
Elevating and Conveying Machinery.				
3 Elevators (iron casings).....	15	1,200	75	150
Conveyors, approximately.....	25	500	50	75
	40	\$1,700	\$ 125	\$ 225
Summary.				
Raw material machinery.....	205	10,950	1,000	400
Calcining machinery.....	25	8,700	515	650
Clinker grinding machinery.....	110	5,500	250	175
Elevating machinery.....	40	1,700	125	225
	380	\$26,850	\$1,890	\$1,550

It is generally estimated that a seven rotary kiln plant with a capacity of 1,200 barrels per day, working limestone and clay, can be put up for \$300,000.

In regard to the cost of producing cement a number of estimates have been published, several of which are given for what they are worth, but the writer declines to express any opinion of them. They should be accepted with caution, as they all tend to underestimate the actual cost.

Estimate No. 1, Limestone and Clay.

Limestone crushed.....	per barrel	\$0.05
Clay.....	per barrel	0.02
Labor.....	per barrel	0.15
Fuel.....	per barrel	0.20
Supplies and repairs.....	per barrel	0.12

Cost per barrel, not including office and selling expenses..... \$0.54

Estimate No. 2, Cement Rock and Limestone.

Maximum capacity 2,000 bbls. per day, average capacity 1,200 to 1,300 bbls.

Help needed:

Crushing and drying.....	for each shift,	2 men
Raw and clinker grinding.....	for each shift,	6 men
Coal grinding.....	for each shift,	3 men
Rotary kilns.....	for each shift,	6 men
Power house.....	for each shift,	5 men
Unloading coal, stone, etc.....		12 men
Machine shop, electricians, smiths, and bricklayer.....		12 men

For laboratory and office expenses 2 cents per barrel is reckoned.

The coal for firing the kiln is 13.35 cents per barrel, for the boilers and dryers 10.9 cents per barrel.

The total cost per barrel would now be distributed as follows:

Labor:

Quarry.....	\$0.050	
Crushing and drying.....	0.005	
Grinding.....	0.015	
Burning.....	0.015	
Power generation.....	0.011	
Coal grinding.....	0.010	
Yard work.....	0.015	
Machine shop.....	0.0225	
Miscellaneous.....	0.0025	\$0.15

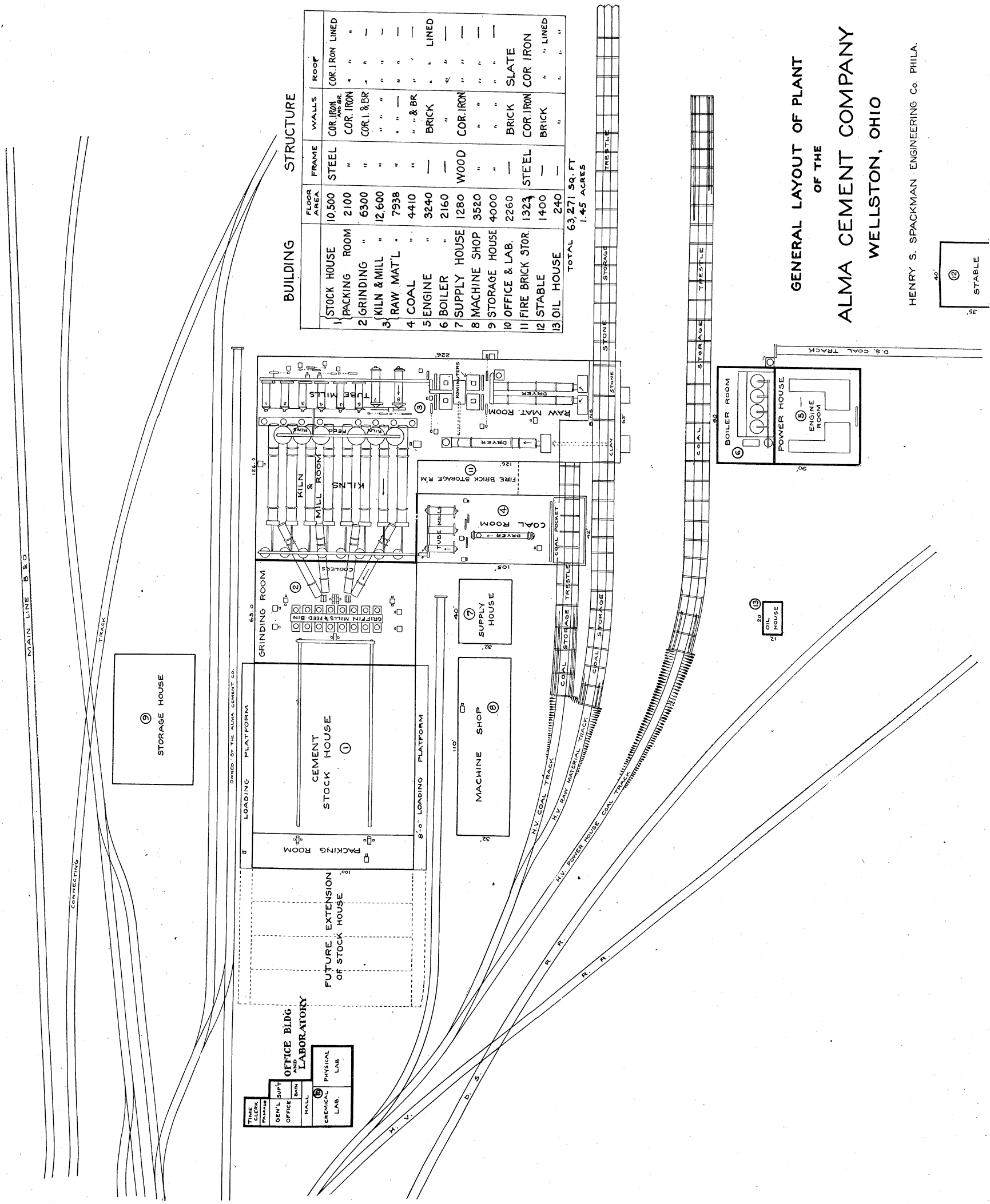
Raw Materials:

Coal.....	0.2250	
Gypsum.....	0.0125	0.245

Accessory Expenses:

Repairs.....	0.04	
Oil.....	0.02	
Miscellaneous.....	0.03	0.09
Packing and loading.....	0.04	
Works management.....	0.02	0.06
Interest on investment (\$700,000).....	0.07	
Sinking fund and deterioration.....	0.10	
Management and selling expenses.....	0.065	0.235

Total..... \$0.7775



GENERAL LAYOUT OF PLANT
OF THE
ALMA CEMENT COMPANY
WELLSTON, OHIO

HENRY S. SPACKMAN · ENGINEERING Co. PHILA.

40'
STABLE
(12)

In volume VIII, Michigan Geological Survey, the following figures are given regarding the cost of making cement in a marl and clay installation, by the wet process: the burning is estimated at 17.2 cents per barrel, the clinker grinding at 8.8 cents, the power at 9.3 cents and the packing at 2.55 cents per barrel. The average cost of making cement in Michigan is estimated at 68 cents per barrel.

OHIO PORTLAND CEMENT PLANTS.

The writer has visited all the cement plants of Ohio with one exception and was received with courtesy and consideration in every plant visited. The pioneer plant of the State is that of the Sandusky Portland Cement Co., at Bay Bridge. Permission to visit this plant was refused, hence no description can be given of its equipment or arrangement.

The largest cement works of the State, the Castalia Portland Cement Co., is located at Castalia, 6 miles south of Sandusky, in Erie county. The raw materials are a very pure travertine, and a soft clay. The travertine is the only deposit of the sort worked in the United States. The wet process is used, the materials being run through a wet plan and tube mills. After being ground the slurry is pumped into large tanks by means of compressed air and the composition corrected by the addition of high lime or high clay correction slurry. The burning is done in 13 rotary kilns. The clinker is ground in ball and tube-mills, and two Griffin mills are also installed. The coal is ground in Griffin mills. The power available is 1,700 horsepower. The average capacity is 1,500 to 1,600 barrels of high grade cement. A view of this plant will be found on page 332, for which the writer is indebted to the company. The offices of the company are at Pittsburg, Pa.

In Stark county, at Middle Branch, we find the Diamond Portland Cement Co. using the Putnam Hill limestone and the shale associated with it, of which, however, part is rejected and dumped. This mill has a capacity of about 600 barrels per day, using 8 to 10 feet of the shale and 6 to 7 feet of the limestone. The limestone is crushed by Aultman rock crushers and then passes through a rotary dryer, roller crushers, and is ground fine by Emery mills. It is then stored in large tanks, 28 feet by 10 feet, being thoroughly sampled in these and analyzed.

The shale is put through a dry pan, a rotary dryer, and is ground fine like the limestone and is also stored in large tanks where its average composition is determined. The limestone and shale are then weighed out by means of a bucket and crane and ground together in large ball-mill mixers. The mixture is hence positive and is bound to be correct. The mixed constituents are then conveyed to a large storage tank, which feeds a pug-mill and auger brick machine where stiff mud bricks are made and stacked on iron cars. These are run on tracks into a steam tunnel dryer and dried thoroughly. The dried bricks are

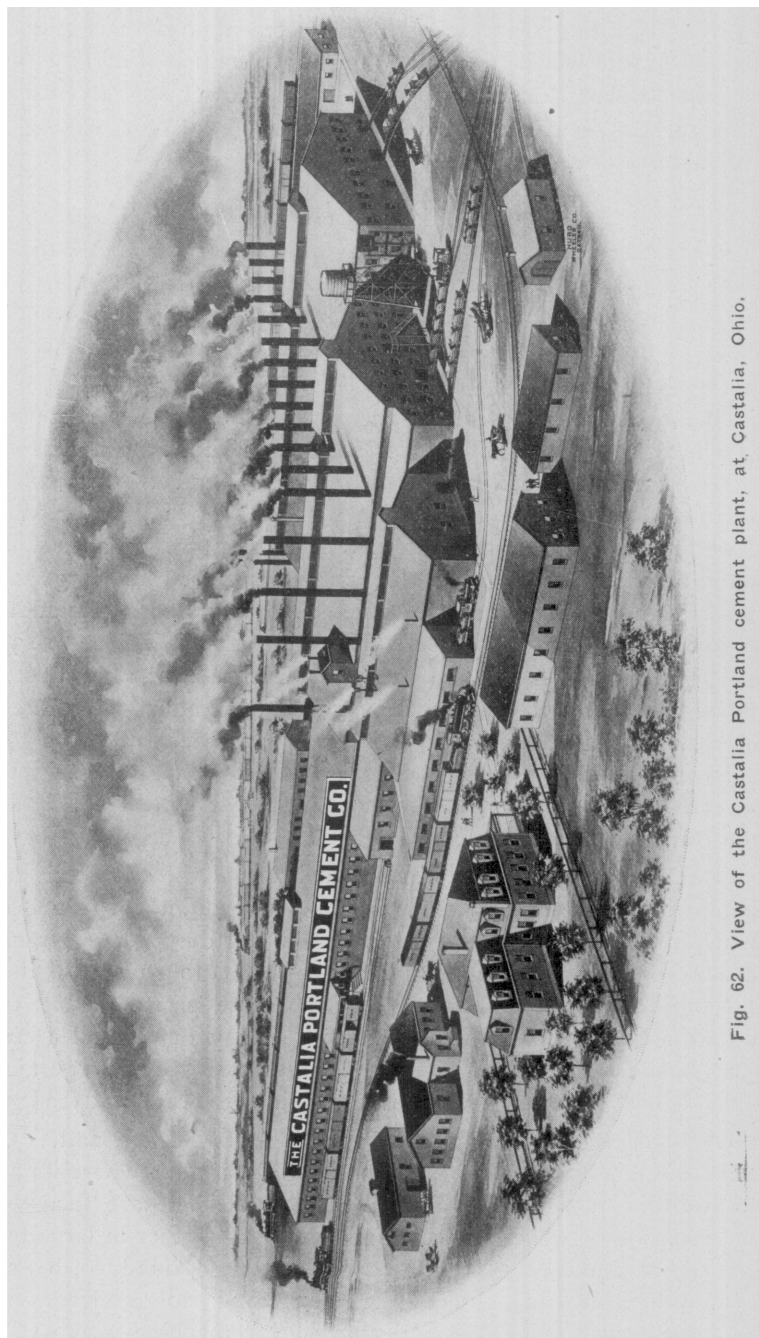


Fig. 62. View of the Castalia Portland cement plant, at Castalia, Ohio.

hoisted and dumped into three large, double Dietzsch shaft kilns, where they are burnt to vitrification. The clinker is crushed in an Aultman reducer and ground in ball and tube mills. Packing machines are used. The chemical and physical laboratories are exceedingly fine and well equipped.

Extensive changes have recently been made in the plant, bringing in the most modern features.

In Logan county there are two plants, one the old established works of the Buckeye Portland Cement Co. at Harper, the other a newer concern, the Alta Portland Cement Co., at Rushsylvania. The Buckeye works represent a gradual growth from the German type of plant to the new American method. First, a double Dietzsch kiln was used, to which later were added four continuous shaft kilns patterned after the kiln designed by Candlot, France, and still later rotary kilns were installed. The raw materials are a fine grained marl and very fine glacial clay. Two methods were employed when the writer visited the plant, one supplying bricks to the shaft kilns by blending the clay and marl in a wet pan and making the bricks on an auger machine, which are then dried and taken to the kiln, and the other producing slurry for the rotaries by grinding in a wet grinder. The slurry is pumped into storage tanks, kept agitated, and from these to the rotaries. The clinker is crushed by roller crackers and finished in part by mill stones and partly by tube mills. At one time producer gas was used for burning one rotary kiln, which was a success, but not as economical as coal dust firing. This plant recently has undergone further changes and has received many new features. The marl is dredged and hauled to the factory in tram cars.

The works of the Alta Portland Cement Co. are but two miles distant from the Buckeye plant and practically the same raw materials are worked, which are hauled by a steam locomotive in iron dump cars. The slurry process is used, the grinding being done in two tube mills which feed two rotary kilns. Storage tanks provide for a good reserve stock of ground raw material. The clinker is ground in ball and tube mills and the coal by an æro pulverizer. The cement stock house consists of three stories, the cement gradually falling from one story to the other, thus giving it a better chance to cure. At this plant the raw materials are dug by hand. The capacity is about 300 barrels per day, the available power being 300 horsepower.

At Wellston there are also two plants, the Alma Cement Co. and the Lehigh Portland Cement Co., formerly the Wellston Portland Cement Co. The first, destroyed by fire several years ago, has been rebuilt with the most modern improvements. The accompanying plan of this mill shows the arrangement of the machinery and kilns and hence needs no description. The dry process is used; the raw materials are limestone,

shipped several miles from Cornelia furnace, and a clay obtained near the plant. This company also owns its own coal lands; hence the fuel question is not a troublesome one. The laboratory facilities are generously provided for. As to shipping facilities, they could not be improved upon, and there are probably few cement works who can boast of as many connections with different railroads. This shows the wisdom of building the plant at this place instead of erecting it at the limestone quarry. The mill has 8 rotaries and an approximate capacity of 1,400 barrels. For the plan of the works the writer is indebted to the Henry S. Spackman Engineering Co., Philadelphia, who constructed the plant.

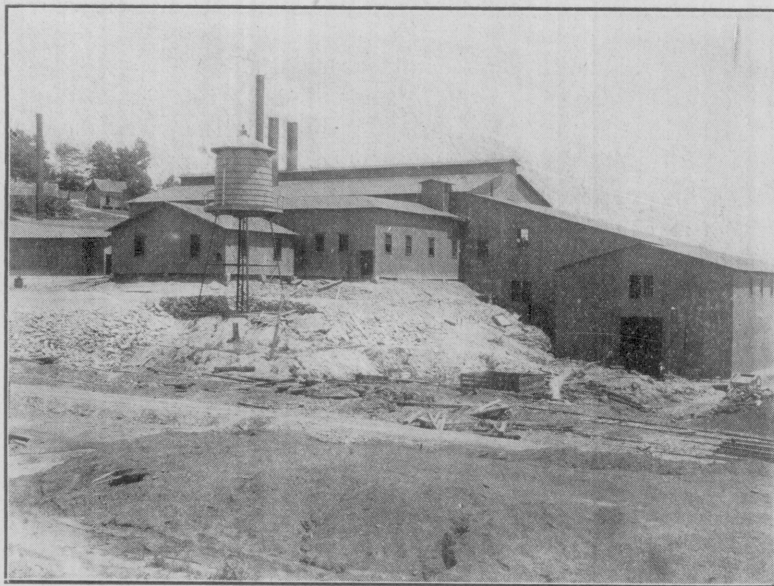


Fig. 63. View of the Lehigh Portland cement plant, at Wellston, Ohio, when first constructed.

The Lehigh Portland Cement Co. works practically the same raw materials. The stone and clay pass through a Gates crusher together and then through a rotary dryer; from here the mixture passes through a Williams pulverizer into tube mills driven direct by electric motors. The rotary kilns are 60 by 6 feet. The clinker is ground, or was at the time of the visit, by a Williams mill and tube mills. Electrical transmission is used throughout and hence no belts are seen except in engine house. The available power is 700 horsepower.

At Ironton a new plant has been erected, that of the Ironton Portland Cement Co., using the limestone found at this place, and clay. The materials are ground in a Gates crusher, a Williams mill and tube mills, and the clinker passes through a Kent mill, replacing ball-mills, and finally through tube mills.

Electric transmission is used satisfactorily and flexible connecting shafts have proven very successful. The raw materials are dried in a rotary dryer. The capacity of the plant is about 500 barrels per day.

The southeastern part of Ohio offers a good field for the establishment of cement plants, owing to the cheap raw materials and especially cheap coal, together with good shipping facilities. It is a field which is bound to be more and more developed as the confidence in the cheapness of the dry process increases, and it is more fully realized that dry grinding produces a cement equally as good as the marl cements made by the slurry process.

CHAPTER IX.

THE PROPERTIES OF PORTLAND CEMENT AND THE TESTING OF CEMENT.

The subject will be considered under the following headings:

1. Hydration and heat of hydration.
2. Setting and hardening.
3. Tensile and crushing strengths.
4. Constancy in volume.
5. Specific gravity.
6. Fineness of grain.
7. Some physical and chemical constants.
8. The effect of various reagents on the properties of Portland cement.
9. The enduring qualities of Portland cement with special reference to the action of sea water.
10. American standard specifications.

HYDRATION.

1. On adding water in proper quantity to Portland cement it is found to stiffen gradually until it becomes so hard that the mass cannot be penetrated by a rod. Under the microscope white, needle-like crystals of calcium hydrate are seen to grow rapidly, and the grains of cement appear to swell, forming a mass of colloid particles. The phenomenon of hardening must, in the nature of the case, be strongly analogous to the crystallization of supersaturated solutions.* The more the crystal surfaces in contact are developed, the greater the total adherence and the strength of the mass. Crystals in long plates or in interlocked fibers should give greater strength than blunt and heavy crystals. But the result of this crystallization depends on many factors, the degree of supersaturation, i. e., the amount of water present, the fineness of the salt and many other conditions. At the same time the production of the colloid particles, distinct from the crystals of lime hydrate, raises the question whether the hardening due to hydration might not be due to the drying of the greater mass of colloid material. This question has not as yet

**Chatelier, Engineering Congress, Chicago, 1893, Trans. Am. Inst. Min. Eng., 1893.*

been answered and we do not know whether the resulting hardness is due to the sum of the effects of the crystallization and the colloid hardening or of one of the two, just as we are in ignorance as to the cause of the plasticity of clay, in regard to which, however, the colloid theory is offering the most powerful evidence.

On the other hand it has been shown that when cement is made up with water, its electrical conductivity is much greater if a current is conducted through it than if the latter were simply passed through the solution which was in contact with the cement, and in which the latter had been thoroughly shaken. At the moment of hardening the electric resistance increases enormously. This thus offers some additional evidence in favor of the supersaturation theory. Whatever the results of the hydration may be, we know that the crystalline mass of the hydrolite breaks down by hydration to simpler compounds and calcium hydrate. We have hence a certain amount of water of hydration. At the same time a slight increase in temperatures is observed; that is, some heat of hydration is evolved. The amount of water of hydration found in Portland cement varies greatly and depends on the conditions of fineness, the amount of water added, etc. The writer, by heating hardened cement pats in a hard glass tube in an atmosphere of air freed from carbon dioxide and water, up to red heat, was unable to obtain consistent results. On using a little more or less water, making a larger or smaller pat, different amounts of water of hydration were found. Zulkowski takes 14.67 per cent. of water to be theoretically correct for ideal Portland cement. S. B. Newberry found from 10 to 27 per cent. of water, Feichtinger 11.56 per cent. Probably Zulkowski is nearest to the truth, especially since one of his assistants actually found in a Portland cement 14.44 per cent. of water of hydration.

In regard to the heat of hydration a number of commercial American Portland cements were taken and tested in the calorimeter already described, using from 5 to 10 grams in 100 cc. of distilled water. The results obtained were as follows:

Number.	Calories per gram.	Number.	Calories per gram.
1	1.79	8	5.56
2	1.19	9	3.43
3	0.47	10	6.41
4	2.00	11	1.35
5	0.50	12	3.98
6	2.10	13	1.04
7	2.20	14	1.19

No attempt was made to take into account the heats of the solution.

We note here values running as high as 6.41 and as low as 0.47 per cent., but considering the many possible factors entering into the reaction it is a significant fact that the thermal values are quite low, not exceeding 10 calories. Now we might be led to the general conclusion that the higher calorific values are simply due to the hydration of the excessive amount of calcium oxide present. But we have no right to make such an assertion, and, furthermore, experiments quoted elsewhere have shown that the amount of lime contained in a cement stands in no direct relation to the heat evolved. Certain factors like the amount of silica present have a great influence on the heat of hydration. But taking the same cement, with the same clay base, the case is different. Here we may be able to detect any uncombined lime due to insufficient curing or underburning, and, hence, for a given cement we can establish a certain thermal limit and the calorimeter becomes a valuable aid. The significant fact is also to be noted here that aluminous cements show high heats of hydration which drop at once as soon as the clay base is enriched in silica. It cannot be denied that in doubtful cases where the boiling test is questioned the calorimeter is able to give important contributory evidence. The calorimeter or an equivalent instrument should therefore form a valuable adjunct of every cement laboratory. Tetmayer has designed an instrument which is to be used in conjunction with the Vicat needle, which consists of a hard rubber casing and rubber cover, through which the thermometer is inserted and its readings noted, while in the meantime the time of setting is observed by means of the needle. This test is employed by a good many cement manufacturers, and the writer was told by several superintendents that they never allow cement to leave the stock house unless its rise in temperature on setting falls below a given limit. It is a curious fact that a second rise in temperature takes place with some cements, which often is quite considerable, up to 7 or 8 degrees Centigrade. Just in how far this is related to the setting has not yet been determined. The curves of figure 64 show the temperature changes observed in four American cements.

SETTING AND HARDENING.

These two stages must be clearly distinguished. The first represents but a short period, from 15 minutes to 12 hours, while the second may extend for a period of years. If cement is made up with from 25 to 34 per cent. of water, mixed thoroughly for about three minutes and made up into a pat, it will be found that after some time it begins to stiffen so that it becomes more and more difficult for a needle to penetrate into the mass. This first period of the hardening we call setting and its beginning is determined by the point at which a wire, 1-12 of an inch in diameter, loaded with $\frac{1}{4}$ pound, is supported by the cement without in-

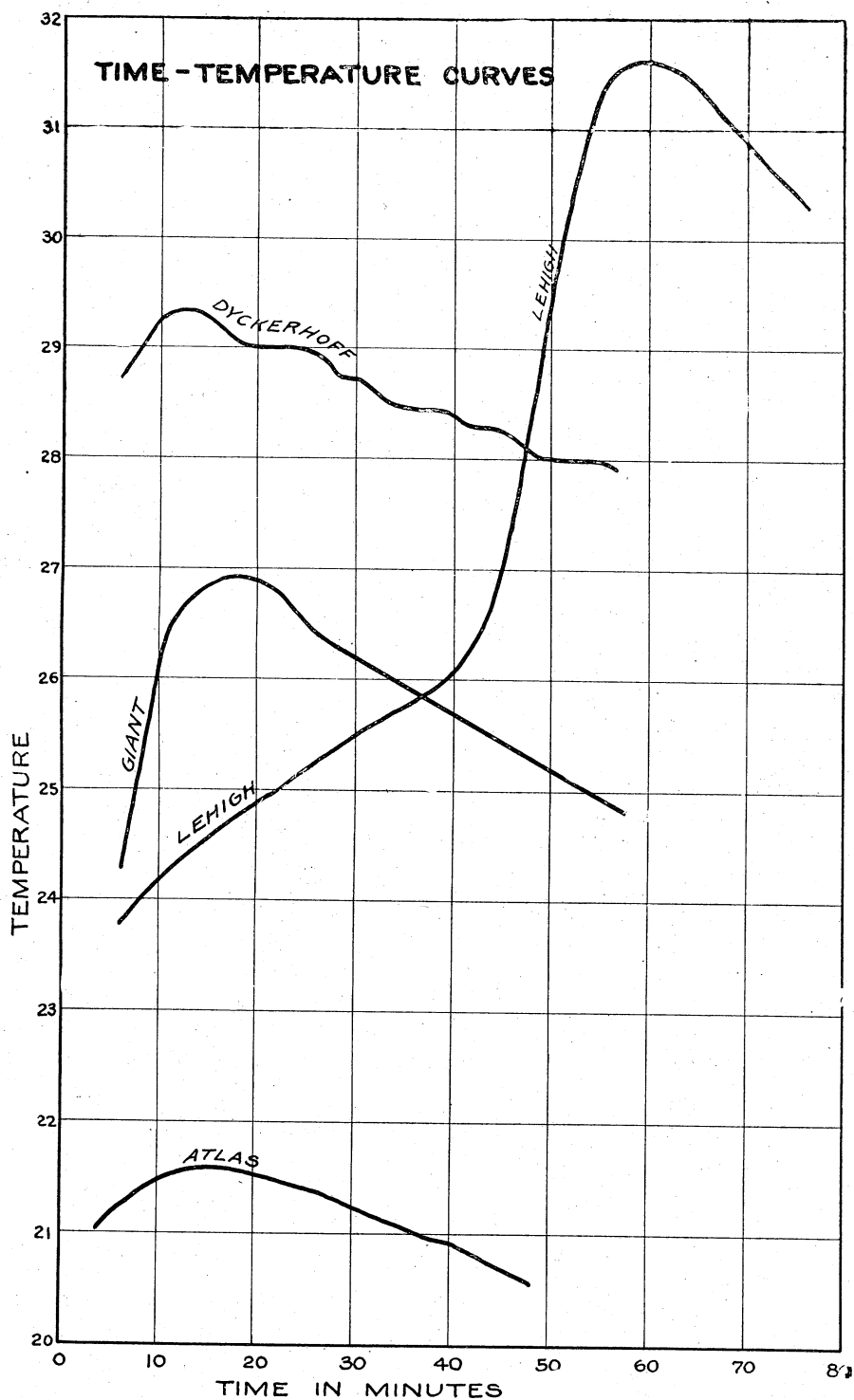


Fig. 64. Curves showing heat evolved in setting, as observed in four typical American plants.

denting the surface, while the close of the setting is fixed by the point at which a wire 1-24 of an inch in diameter no longer indents the cement. Starting from this condition the cement gains in hardening for one or more years. In European practice the Vicat needle is employed exclusively for the determination of the time of setting. This instrument consists of a weighted cylindrical rod which slides up or down in guides and is provided with an indicator and set screw. (See Fig. 79, p. 372). The cross section is 1 sq. cm. and the weight of the rod is 300 grams. The cement is molded in a conical receptacle, 65 mm. in diameter on top and 75 mm. at the bottom and 40 mm. high. If the rod penetrates 5 to 7 mm. the cement is said to have standard consistency. The lower part of the rod is now replaced by a needle 1 sq. mm. in cross section and enough weight is added to keep the total weight equal to 300 grams. As soon as the needle cannot penetrate the cement complete setting is said to begin, and when it cannot penetrate the mass at all the final setting is considered finished. Some advocate the use of thermometric measurements in place of the needle tests, considering the setting finished when the temperature of the cement begins to fall. This, however, is quite liable to be erroneous and deceiving.

The rapidity of the setting of cement is influenced by a number of factors, which are as follows:

1. Amount of water used.
2. Temperature of water and air.
3. Fineness of the cement.
4. Composition of the cement.
5. Time and manner of curing cement.
6. Catalytic agents added to the cement.
7. Composition of the water.

In brief, the more water is added above the amount required, the slower will be the setting.

Warm water invariably hastens the setting and it has been found by Erdmenger that lukewarm water also increases the ultimate strength of the cement. Boiling water, on the other hand, decreases the strength of the cement, owing to increased porosity. Cold water causes the setting to take place more slowly, as we find it to be true in most of the chemical reactions.

Fine cement invariably sets faster than coarse cement.

As we have seen already, aluminous cements set very quickly, as well as cements high in lime, while, on the other hand, silicious cements tend to set slowly.

Cement fresh from the kiln is much more rapid than cement which has been cured. This is due to the slaking of any uncombined lime as well as to the absorption of carbon dioxide. Cured cement when heated strongly resumes its initial rapidity of setting. Slow setting cement

exposed to the sun frequently becomes quicker in its action. This is due to the breaking down of the coarser particles to dust, a tendency shown by practically all cements, for even coarse clinker will in time break down to a powder.

It has been known for a long time that small amounts of certain salts added to Portland cement affect the time of setting in a most decided manner. Thus the effect of different chlorides added to a Portland cement, whose setting time was 12 minutes, was as follows:

Name of Substance.	1 per cent.	2 per cent.	3 per cent.	4 per cent.	5 per cent.	6 per cent.
	Minutes	Minutes	Minutes	Minutes	Minutes	Minutes
Magnesium Chloride.....	29	35	55	75	120	260
Barium Chloride.....	45	125	200	340	465	580
Sodium Chloride.....	32	65	100	150	270	330
Ammonium Chloride.....	31	45	85	100	200	270

Some contradictory facts are, however, noticed in this connection, Thus a dilute solution of calcium chloride retards the setting, a concentrated solution accelerates it. Soda and potash solutions accelerate the setting.

The best work on this subject has been probably done by Dr. Rohland, who ascribes the action of various small amounts of salts to catalysis and gives expression to the following statement:

Where the velocity of reaction setting is very slow the catalytic agent produces a greater effect than when the velocity is greater. Positive (accelerating) and negative (retarding) reagents may neutralize each other. The quantities may be very small; 1 per cent and less is often sufficient to produce great changes. He makes a list of catalytic agents including:

Calcium sulphate,	—
Aluminum chloride,	+
Sodium carbonate	+
Calcium chloride	+
Barium chloride	+
Potassium bichromate	—
Sodium chloride	o

He also brings out the fact that aluminates in cement may decompose on storing and thus bring about changes in the rate of setting, so that sometimes in spite of curing the cement becomes quicker setting. The

best example of catalytic action we have in the addition of gypsum to the ground clinker.

It has been found by experience that hard water tends to retard the setting, which also applies to sea water.

In general it may be said that slow setting cements result as a rule in stronger and more consistent cements than quick setting cements. The same statement also applies to the hardening. Cements which assume their maximum hardness in a short time are liable to go back in their strength, as has been shown by many tensile and crushing tests.

TENSILE AND CRUSHING STRENGTH.

In use, cement is largely subjected to crushing strains, and hence crushing tests would seem the legitimate mode of testing cement, but owing to the expensive apparatus required in making these tests, the tensile strength of a cement is normally taken as the criterion of its strength. Roughly speaking, the crushing strength is from 10 to 12 times the value of the tensile strength.

The tensile strength test is carried out by filling brass molds of the well-known figure 8 shape with a paste consisting of the cement to be tested, either mixed with sand of certain definite quality. The molds are filled either by hand or by means of a machine. The briquettes thus made are kept in moist air for 12 to 24 hours, when they are immersed in water, in which they are kept till it is desired to test them, usually from 7 to 28 days. New cements in regard to which but little is known are tested frequently for longer periods—a year or more.

Testing Machine.—The briquette, whose area at the narrowest point is one square inch, after hardening, is put into the tensile strength testing machine and broken at the weakest point. In American practice the type of machine, like the Fairbanks, Fig 65, in which shot is allowed to flow into a balanced bucket until the pressure, multiplied by levers, is sufficient to break the test piece commonly employed. The flow of shot is stopped automatically on the breaking of the briquette, and by weighing the charge of shot run in the pressure on the briquette may be read off. Other machines like the Riehle depend on the gradual movement of a weight towards the end of a lever till the briquette is broken when the weight has arrived at a certain point. Again other machines employ hydraulic pressure, but the one most commonly employed is the Fairbanks type.

In reporting results of tensile strength tests all values of poorly fractured briquettes should be rejected. In practice the tensile strength results vary as much as 18 to 20 per cent above or below the average and are much less consistent than the crushing strength tests. The effect of the kind of sand upon the tensile strength is exceedingly marked, and variations in the results are greater than in the crushing tests, though, of

course, the general laws governing the sizing of the sand and the porosity with reference to the ultimate strength hold good for both kinds of tests. But, to illustrate, when clay is added to a sand used in making tensile tests the strength apparently is raised considerably, while with the same sand mixture the crushing strength, if it rises at all, shows but a small increase.

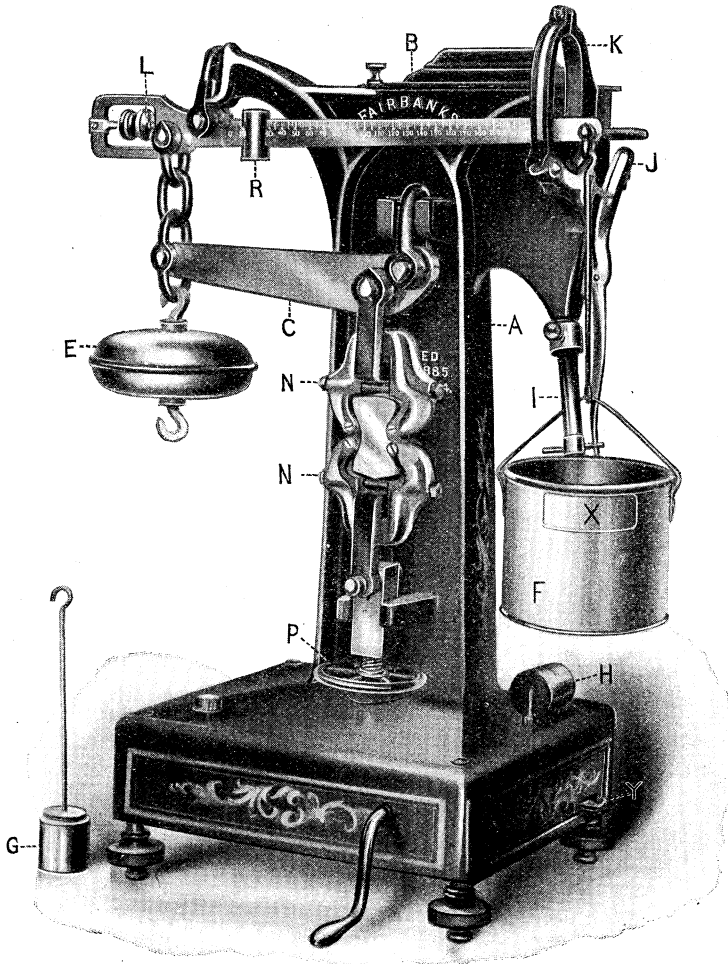


Fig. 66. Amsler-Laffon machine for crushing test.

The tensile strength of neat cement increases up to about one year, but it reaches its ultimate strength quite closely in three months. The tensile strength of the neat cement may vary from 600 to 1,100 pounds after three months in water. The crushing strength of neat cement may vary from 7,500 to 14,500 pounds per square inch after three months. Any decrease in the tensile strength of cement shows the presence of mechanical strains in the test pieces or chemical changes, and such

cements are open to suspicion. Indirectly the tensile strength is a test for fineness of grinding, for, given a certain cement, it will show a greater tensile strength the finer it is ground. Silicious cements are occasionally looked upon with distrust owing to their comparatively low tensile strength in the short time tests. This, however, is due to the slower hardening of these cements and not to any inherent weakness, for they show an exceedingly high tensile strength after three months, the writer recollecting several instances in which silicious cements pulled considerably higher than 1,000 pounds, neat.

On the other hand, aluminous cements show a very high initial tensile strength, but after some time a significant decrease in strength is observed, which not uncommonly results in the destruction of the cement structure. It is, hence, always preferable to use a cement showing a steady increase in strength, though the initial strength may not be high. Very high initial tensile strengths are to be regarded with suspicion and will be found to be indicative of weakness rather than strength. In American practice crushed quartz not coarser than 20 mesh and not finer than 30 mesh is used as the standard sand and though, owing to the large proportion of voids, it does not produce the densest and hence strongest mixture, it affords a uniform standard of comparison. The following table indicates the required tensile strengths in American practice:

A.—Neat cement.

- 1 hour in air, 23 hours in water, 100–140 pounds per square inch.
- 1 day in air, 6 days in water, 250–550 pounds per square inch.
- 1 day in air, 27 days in water, 350–700 pounds per square inch.
- 1 day in air, 364 days in water, 450–800 pounds per square inch.

B.—One part of cement (by wt.) to three parts standard sand.

- 1 day in air, 6 days in water, 80–125 pounds per square inch.
- 1 day in air, 27 days in water, 100–200 pounds per square inch.
- 1 day in air, 364 days in water, 200–350 pound per square inch.

To indicate how American cements run, the breaking figures of a well-known cement might be quoted,* which are interesting, since they represent the averages, of many tests. The briquettes were made of Giant cement, with standard sand in the proportion of 1 cement: 2 sand.

Time.	28 days.	3 mos.	6 mos.	9 mos.	12 mos.
Number of breakings.....	690	215	185	155	165
Aver. break. weight, pounds per sq. inch..	441	563	657	671	663

*C. S. Gowen, *Proceedings, Amer. Society for Testing Materials* July, 1903.

Amount of Water.—The amount of water used in making the mortar has considerable influence on the resulting strength, as is indicated by the following series of tests made by E. S. Larned:*

Portland Cement Brand.	Per cent. of water used.	Initial set. Minutes.	Final set. Minutes.	Tensile strength neat cement. Pounds per square inch.					
				24 hours.	7 days.	28 days.	3 months.	6 months.	12 months.
Giant ...	15	12	207	371	655	875	941	720	787
" ...	16	29	297	303	750	973	1008	735	816
" ...	18	80	355	260	649	773	831	645	748
" ...	20	142	402	233	500	693	716	621	676
" ...	22	268	473	184	546	635	658	601	589
" ...	24	327	912	167	539	649	644	629	755
Atlas	13	13	270	366	775	859	1067	892	832
" ...	14	18	303	404	780	891	972	852	781
" ...	16	22	327	363	602	725	844	806	723
" ...	18	15	383	308	570	723	785	728	724
" ...	20	56	703	225	590	718	760	674	636
" ...	22	52	833	166	554	649	731	643	604
" ...	24	188	918	42	510	691	695	632	574

The proper amount of water to be used with each cement must be determined by experience.

Crushing Machines.—The crushing test is ordinarily performed on a very elaborate and expensive machine which can be employed only in large laboratories and testing stations.

However, there are certain machines on the market that permit of carrying out crushing tests, such as the Amsler-Laffon, which are not too expensive and still give good results. The machine mentioned is hydraulic in principle and uses as liquid heavy glycerine which does not leak between the piston and the cylinders. Pressure is applied by moving the piston by means of a geared crank and compressing the liquid. The pressure is indicated by a mercury manometer. In principle as well as in design this machine is a most excellent apparatus, eliminating the usual errors of hydraulic machines of this kind most completely. It de-

**American Society for Testing Material*, July, 1903.

scrves much more extended use than it has been receiving so far in American practice.

Crushing tests are superior to tensile strength tests in more than one respect. They not only indicate the true strength of the cement, but also are not so liable to experimental errors.

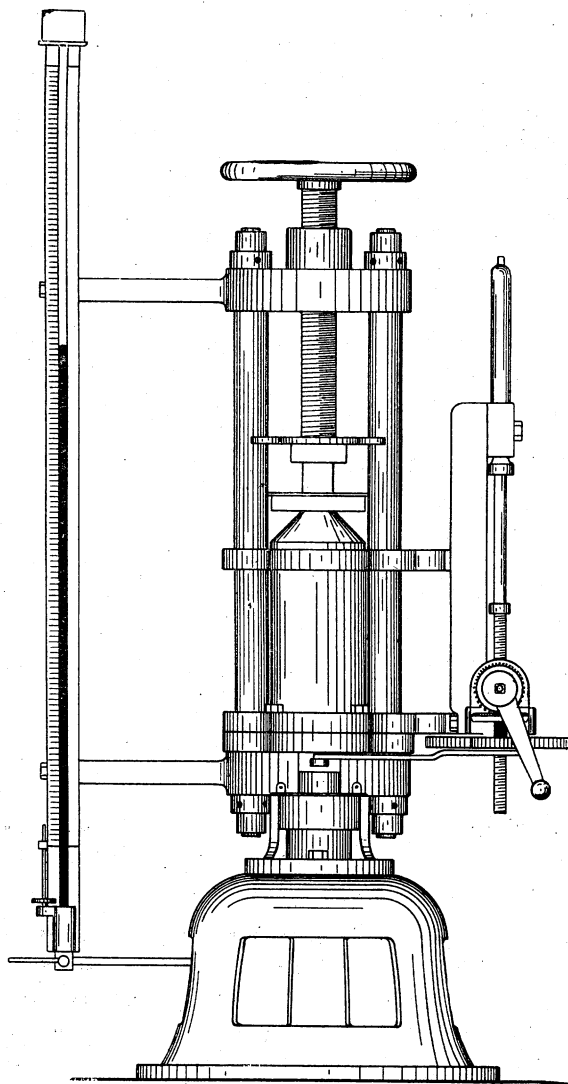


Fig. 66. Amsler-Laffon machine for crushing test.

Larger hydraulic machines for testing concrete cubes are now also on the market at prices within the reach of many testing laboratories. Testing machines depending on screw pressures and spring manometers are as a rule less reliable than the hydraulic machines.

Both the tensile and crushing strengths vary with the same cement, due to the influence of several important factors, which are:

1. Amount of water used.
2. Kind of sand employed.
3. Mode of preparing the test piece.

Amount of Water.—In German practice the proper proportion of water for a given 1:3 mixture is determined by mixing the sand and cement, dry, in a standard mixer, adding water, mixing wet for $\frac{1}{2}$ minute,

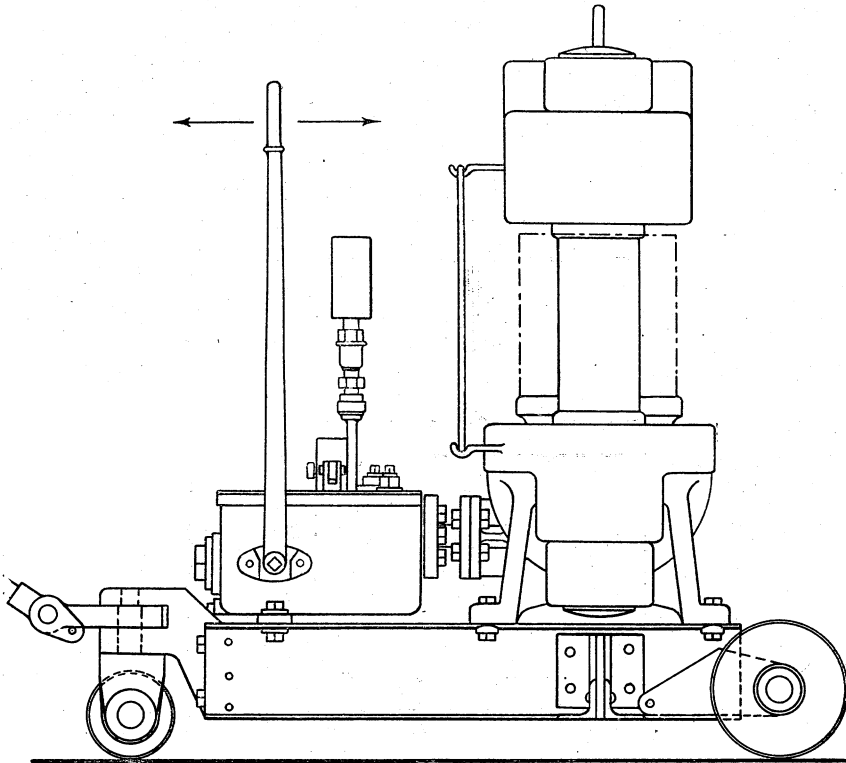


Fig. 67. Portable machine for crushing large concrete cubes.

and transferring to a cubical mold provided with a top plate. This plate is now subjected to a number of blows from a standard hammer and if between the 90th and 110th blow cement paste begins to leak out of the mold box the amount of water is considered sufficient. If not, another batch of cement is made up with more water. By experience, however, it becomes possible to tell without any elaborate apparatus just when the proper amount of water has been added. If an insufficient amount of water is used, hydration will not take place to its full extent and hence the cement will be weaker than its normal strength. If too much water is used the resulting porosity will be too great and hence the strength is again decreased.

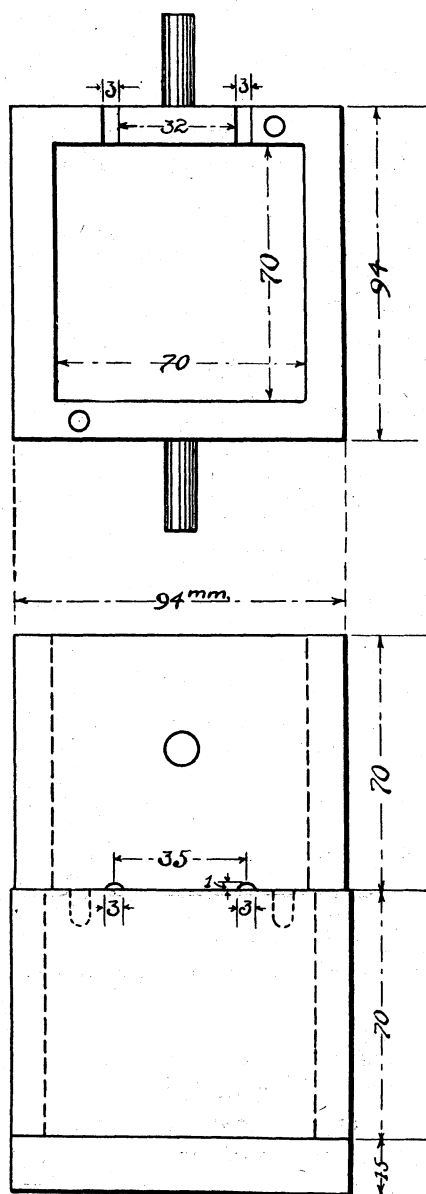


Fig. 68. Mold and die in which the correct consistency of Portland cement sand mixtures is determined; water must begin to leak out at issue-holes, after certain number of blows from standard hammer.

Sand.—In mortar tests, both for crushing and tensile strength, the kind of sand employed is of vital importance. Probably the most important work on this point has been done by Feret, who has carried out an enormous number of carefully made tests endeavoring to determine the relation between the volume of sand and cement and the resulting strength. His results are expressed in the simple formula:

$$P=K\left(\frac{c}{w+h}\right)$$

in which P is the crushing strength in kilograms per square centimeter, K a coefficient, depending on the kind of cement used, c, w and h are the volumes of cement, water, and pore space expressed in terms of the absolute volume, weight divided by specific gravity. Water plus pore space may also be expressed by: volume, 1, minus cement, plus sand, or

$$P=K\left(\frac{c}{1-(c+s)}\right)$$

What remains is water and pore space, assuming always that the mortar is plastic. Feret finally arrived at the formula:

$$P=K\left(\frac{c}{1-s}\right)^2$$

In these formulae s=sand.

By using a number of mixtures under exactly determined conditions and employing an inert sand, not a material containing clay or pozzuolane, the value of K for any cement may be readily determined. Its approximate value is 1965. It is thus seen that the kind of sand is one of the principal functions of the strength of Portland cement mortars. Feret, himself, maintaining the same volume of cement, but changing the sizes of sand, was able to produce fluctuations in strength of over 150 per cent.

Modes of Making Briquettes.—Since the mixing of the sand and cement is done in the dry condition, it does not matter very much what means are employed for this purpose. The blending of the cement with water, however, is subject to variations by different manipulators, and hence for producing standard conditions various mortar mixers have been suggested and used. One of the best known is probably the Steinbrueck mixer (see figure 67). It is still more important, however, that the briquette be put into the mold under as uniform conditions as possible and for this purpose several devices have been used. The Boehme hammer is largely employed in Europe and consists principally of a balanced steel hammer, weighing 4.4 pounds, which is allowed to drop onto a metal part fitting the briquette mold. By means of a cam wheel the hammer is allowed to drop about 10 inches. In 15 revolutions the hammer makes 150 blows and the apparatus is stopped automatically at this point.

In regard to the errors of the tensile and crushing strengths it has been found by Professor Martens that under the most favorable conditions possible the mean error of the tensile strength test is from ± 3 to ± 5 per cent., that of the crushing strength tests from ± 1 to ± 3 per cent.

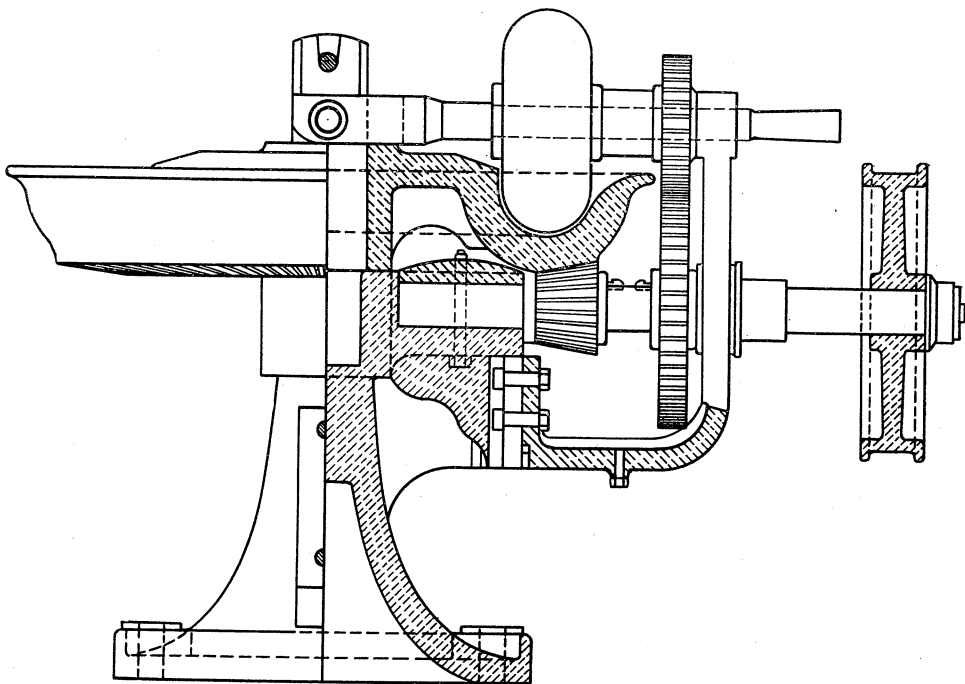


Fig. 69. Steinbrueck mixer for preparing cement mixtures for test.

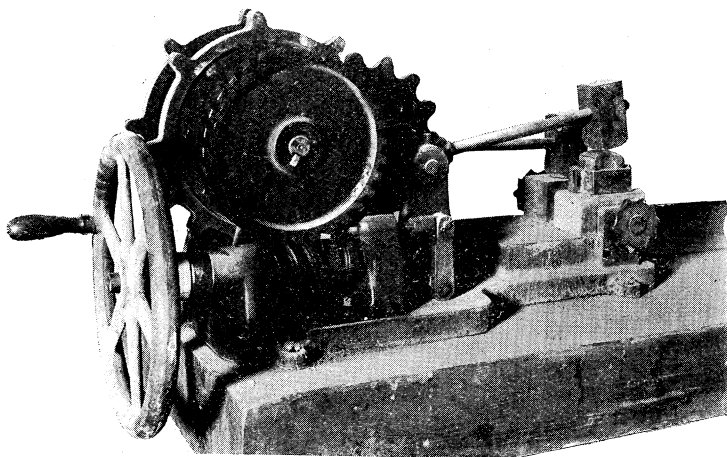


Fig. 70. Boehme hammer, for compacting cement in molds with uniform density.

In order to illustrate, first, the relation between tensile and crushing strength, second, the strength of neat and sand mortar, and, third, the relation between water and air hardening, the following results obtained by Tetmayer are given, representing the average strengths of 16 Swiss Portland cements:

Time of hardening.	Kind of mortar.	Condition of hardening.	Tensile strength lbs. per sq. in.	Crushing strength lbs. per sq. in.	Ratio of crushing to tensile strength.
7 days.....	neat cement	in water	479	5,754	12.01
28 days.....	do	do	552	8,108	14.69
84 days.....	do	do	593	9,699	16.36
210 days.....	do	do	589	12,547	21.31
365 days.....	do	do	633	14,346	22.67
7 days.....	1 cement : 3 sand	in water	293	3,033	10.35
28 days.....	do	do	372	4,014	10.79
84 days.....	do	do	462	4,970	10.75
210 days.....	do	do	520	5,859	11.27
365 days.....	do	do	604	6,319	10.46
7 days.....	1 cement : 3 sand	in air	314	2,979	9.49
28 days.....	do	do	418	3,935	9.41
84 days.....	do	do	452	4,450	9.85
210 days.....	do	do	508	4,605	9.06
365 days.....	do	do	621	5,143	8.28

CONSTANCY OF VOLUME.

Portland cements are liable to the following changes in volume:

1. Increase in volume when hardening in water.
2. Decrease in volume when hardening in air.
3. Change in volume due to changes in temperature.
4. Decided and irregular increase in volume due to abnormal conditions.

1. It has been found in extensive tests made by Dr. Schumann that of eight cement mortars, 1:3, hardening in water, all showed an increase in volume. Expressed in terms of the linear expansion for a test piece 10 cm. long, the average increase in length was, after 7 days, 0.0123 per cent., after 4 weeks 0.0051 per cent., after 13 weeks 0.0025 per cent., after 26 weeks 0.0029, after 52 weeks 0.0052, after 2 years 0.0016 per cent.

2. When hardening in air the average linear shrinkage of four Portland cement mortars after three weeks was 0.0417 per cent. on a prism of 10 cm. length. This change of volume is, of course, normal and due to the peculiar colloidal properties of cement.

3. The change in volume due to change in temperature cement has in common with all other bodies. The coefficient of expansion of Portland cement concrete is from 0.0000137 to 0.0000148.

4. The irregular increase in volume due to abnormal conditions in the Portland cement is a great source of danger in using cement and may be due to either of the following causes:

1. Excess of lime present.
2. Large amount of alumina present.
3. Coarse raw grinding.
4. Coarse clinker grinding.
5. Presence of excessive amounts of sulphates or magnesia.
6. Underburning.
7. Insufficient storing.

Such a cement is said to be inconstant in volume, and for the detection of such materials many tests have been proposed and a great deal of literature exists on this point. The matter of testing cements quickly in this respect is far from being settled. The most accurate methods of determining undue increase in volume in hardening are based on direct measurements of the expansion and the best known instruments for this purpose are the Bauschinger and the Martens apparatus.

The first is simply a micrometer which measures the length of a bar of cement mortar about 10 cm. long, exact to 1-200 mm. The second instrument measures the length of a bar either in air or water by means of a steel point which touches the specimen on the one hand and is connected with a rhombic piece of steel on the other. An increase in length will move the rhombic tongue, and with it a long pointer. The instrument virtually compares the changes in length of the test piece with those of the steel part, and since the two coefficients are practically alike fluctuations in temperature have but little influence on the exactness of the readings.

Accelerated Tests.—But the use of these instruments requires a long time, and for practical purposes where results must be had quickly and without the use of delicate apparatus they are not very suitable; especially in the hands of the untrained manipulator. For this purpose, hence, other tests have been employed, and of these the following are the most important:

1. Boiling test, 3 to 6 hours.
2. Steam test, 3 to 6 hours.
3. Warm water test, 24 hours.
4. Normal water test, 28 days.

It is the object of these tests to accelerate the slaking of the quicklime, if any be present in the cement, or the breaking down of the aluminates or imperfect hydraulic silicates, and thus bring about the destruction of the cement or produce evidence of disintegration. They are carried

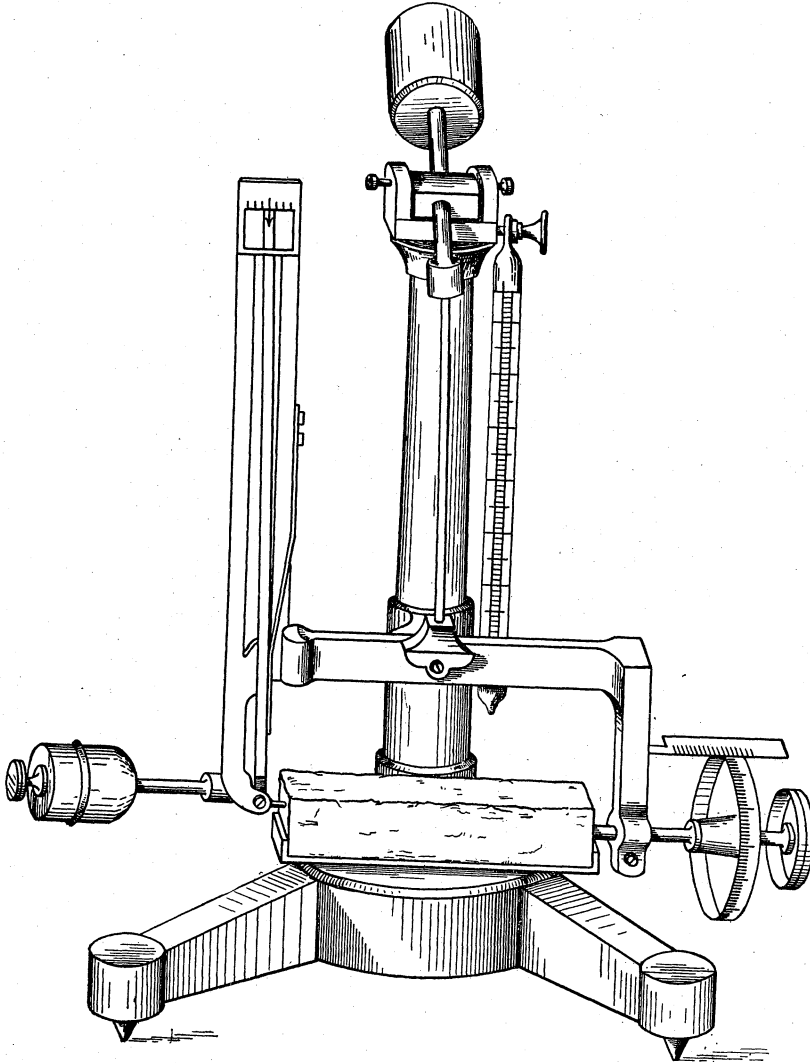


Fig. 71. Bauschinger apparatus for determining constancy of volume.

out by making a pat about 3 inches in diameter and 0.5 inch thick at the center, sloping to a thin edge on a clean glass plate. This pat of cement is then allowed to harden in an atmosphere of moist air for 24 hours. For the boiling test the specimen is put in cold water, which

is gradually heated till boiling and kept so for at least three hours. If the cement is sound the pat, though it may come off the glass plate, should be straight, free from radical cracks, and if a piece is broken off the edge it should break with a clear, sharp sound. If the pat is soft or cracked or partially disintegrated or warped, the cement is not considered sound.

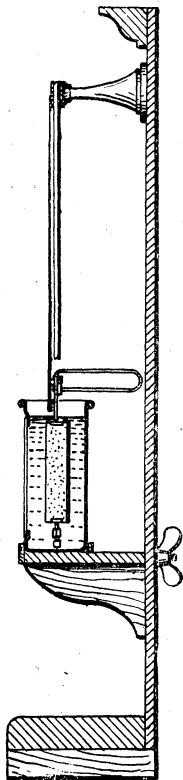


Fig. 72. Vertical section through Martens apparatus for measuring constancy of volume.

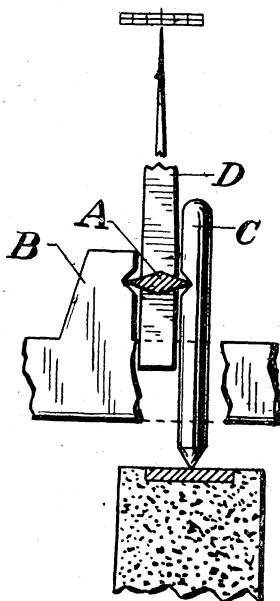


Fig. 73. Partial vertical cross-section through mechanism of Martens apparatus, showing method of transmitting and magnifying changes of length of cement block on which the apparatus rests.

The steam test differs only in that the pat is placed on a wire netting in an atmosphere of steam at about 90° C., without contact with water. This test is not as severe, as it eliminates the mechanical action of the boiling water.

In the warm water test the pat is placed in water at about 45° C. and kept there for 24 hours.

In the normal water test the pat simply remains in water at about 21° C. for 28 days. Any of the evidences mentioned under the boiling test will disqualify a cement. Warping may be detected by applying a straight edge to the surface which was in contact with the plate.

The boiling test is the most severe test and it may be said that, roughly speaking, nine out of ten cements which stand this test will be

found satisfactory in practice, but it is liable to reject cements which are really good. Thus a silicious cement may not pass this test simply because in the 24 hours its hardening has not progressed sufficiently to withstand the mechanical action of the water, while at the same time a rapidly hardened aluminous cement may test normally. In all these tests the mere coming off of the pat from the glass should not count against the cement.

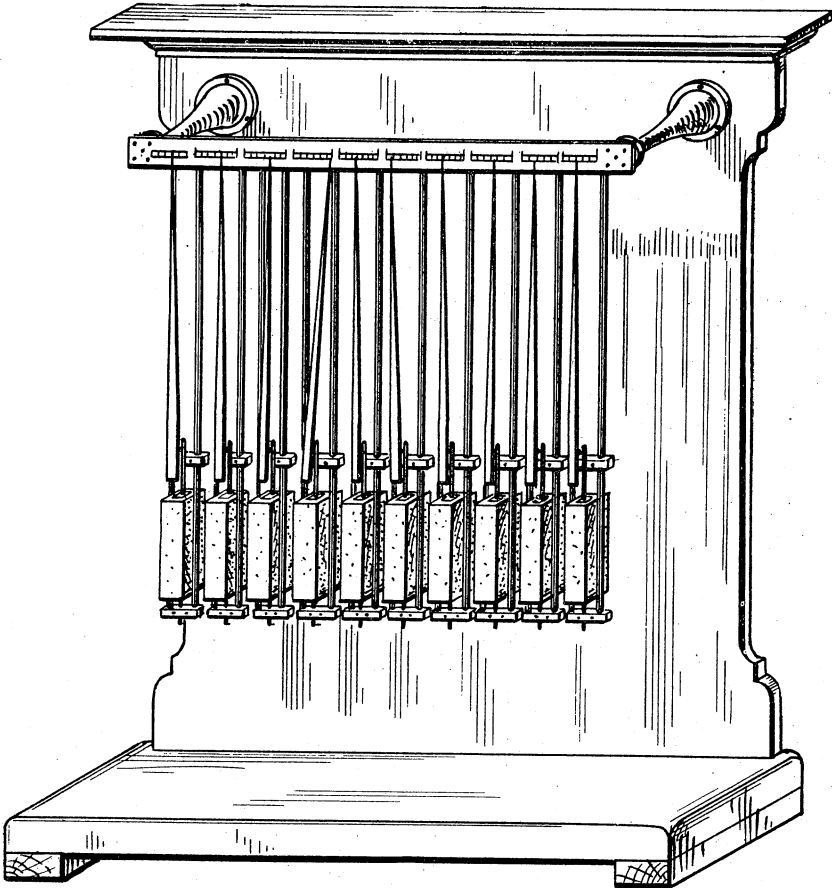


Fig. 74. A Martens apparatus, showing ten cement blocks under observation for change of volume.

The last word has not yet been said in regard to these tests and future work will clear up many difficulties attending our tests for constancy of volume.

In Europe still more rigid tests are practiced, like the hot flame test and the high pressure steam tests.

Calorimeter Test.—An auxiliary test made mention of before is the determination of the heat of hydration. It is well known that aluminous

cements like those containing excess of lime show a high heat of hydration, while the standard Portland cements, as well as cements with a high lime content, but a silicious clay base, have a low heat of hydration. As has been mentioned repeatedly, the number of calories given off on hydration by a cement are not intrinsically a sufficient criterion for judging the quality of a cement, but it is a fact that the standard American cements do not show a hydration value of over 8 calories per gram in excess of water. It has also been found that of cements made by the writer those which showed a high heat of hydration were apt to fail in the boiling test, though not always. The greatest help of this test is in estimating whether or not a cement has been stored sufficiently long. Many Portland cements would stand the hot test satisfactorily if they were allowed to cure longer, and the calorimeter test would thus tend to protect such fresh but otherwise good cements by indicating clearly that further storing is necessary.

The writer added to a sound Portland cement lime ignited to a high temperature in a crucible furnace in percentages varying from 1 to 6 per cent. Boiling tests showed no sign of the breaking down of the cements up to 4 per cent. On making calorimeter tests the heats of hydration determined practically form a straight line, as shown by the accompanying curve (figure 75). The abscissa indicates per cent. of caustic lime added, which was commercial lime, and the ordinate the calories per gram of cement mixture.

SPECIFIC GRAVITY.

The specific gravity of ignited Portland cement varies from 3.10 to 3.25. Storing invariably reduces the specific gravity. It has been frequently claimed that this constant furnishes a criterion in regard to whether the cement has been burnt properly or was underburnt. But extensive experiments have shown that this is not the case, since cement burnt just below vitrification has practically the same specific gravity as the properly burnt cement. It is of use, however, in estimating whether or not a given cement has been cured sufficiently and when this has been determined for a certain cement it affords the chemist a valuable aid in regulating the time of storing.

Overburnt cement shows a lower specific gravity than underburnt cement owing to the vesicular structure developed. It becomes evident, therefore, that the specific gravity does not deserve the general application it now receives except when it is applied to the detection of adulteration.

Specific Gravity Apparatus.—There are many instruments for the determination of specific gravity. The accompanying figure represents the apparatus designed by F. M. Meyer. The parts *a* and *b* are connected by means of a loose rubber tube. Through *h*, about 110 cm. of alcohol (redistilled over caustic lime) is poured in, lowering the bottle *f*. The marks *m*

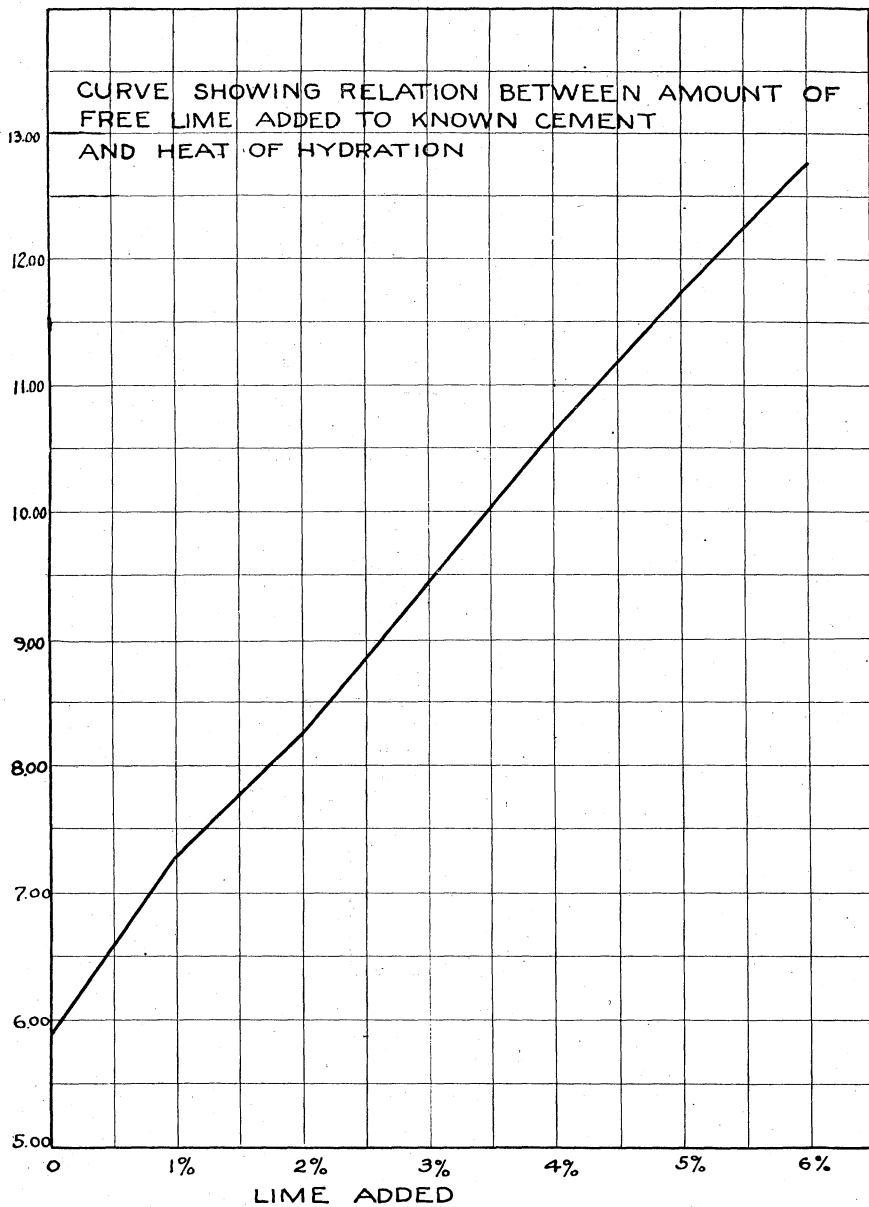


Fig. 75. Curves showing the regularity with which the calorimeter detects and measures the presence of free lime in Portland cement.

and m_1 are now brought to the same height and through the tube of the stopper s as much alcohol is poured as will bring the meniscus just below the marks m and m_1 . By lifting the bottle f the burette is filled up to

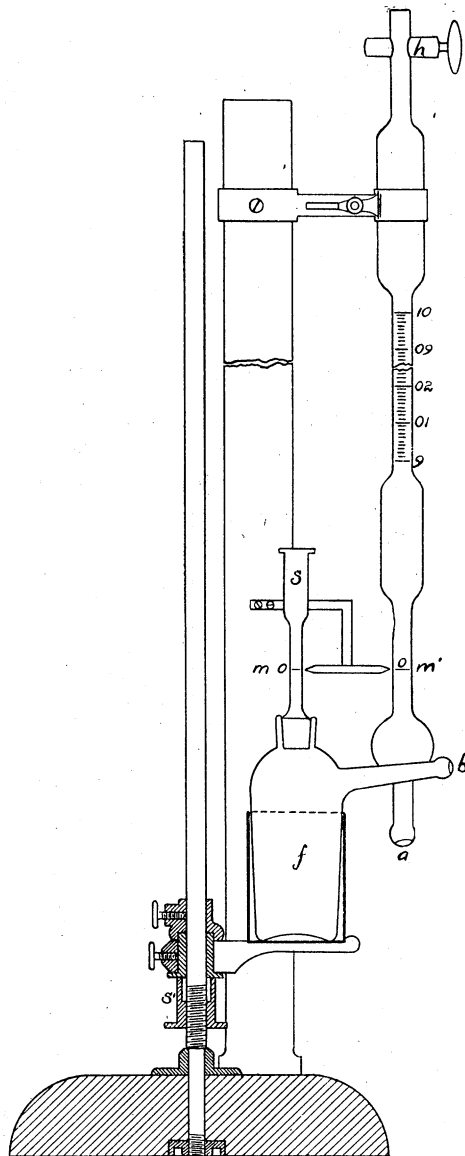


Fig. 71. The Meyer specific gravity apparatus.

the stopcock h , and f , without closing the cock, is brought to its original position. After 5 minutes, m and m_1 by pouring in more alcohol or by means of a micrometer screw are exactly defined. The outside of the stopper is then carefully dried with filter paper, f , raised till the alcohol

is close to the stopcock, h , and the latter closed. The stopper, s , is now removed and 30 grams of cement poured into the bottle, shaking it somewhat. The stopper is now replaced, h opened and f lowered till the alcohol reaches the mark m . After 3 minutes the volume of the cement can be read off the burette. From the volume and the weight of the cement the specific gravity is readily calculated from the formula

$$s = \frac{g}{v}$$

or it may be read off from a table. In this formula s represents the specific gravity, g the weight of the cement and v the volume displaced.

Liter Weight.—A constant of considerable significance, though not generally employed, is the weight of unit volume of cement, say one liter,

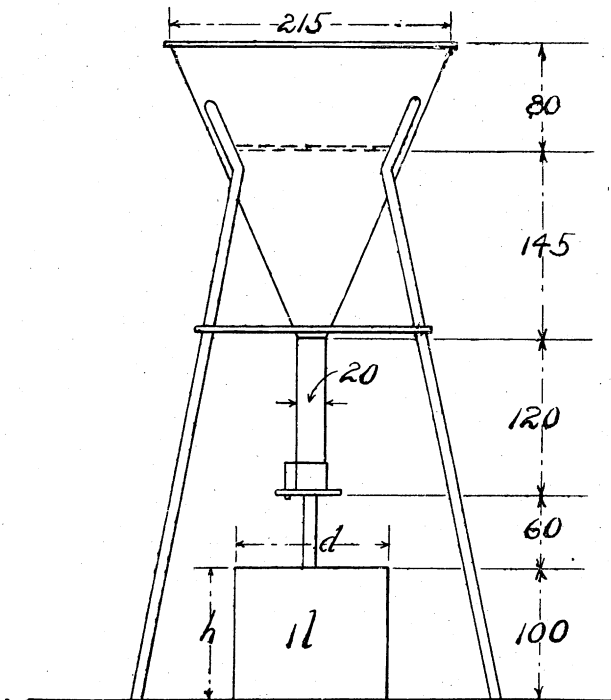


Fig. 77. Apparatus for determining weight of one liter of cement.

the cement being loose in the vessel employed for this purpose, not shaken. The liter weight is determined by placing a funnel over a copper vessel whose diameter is equal to its height and which contains exactly one liter. The lower part of the funnel is provided with a coarse sieve and the bottom of the funnel tube is 5 cm. above the edge of the vessel. Cement is now poured into the funnel in small quantities and when a cone is formed touching the funnel tube the excess of cement is scraped

off and the vessel, together with the cement, weighed. A sketch of the apparatus is shown in Figure 77.

FINENESS OF THE GRAIN.

All cement specifications include the point of fineness of grinding, as it is now generally recognized that the finer the cement is the more complete will be its hydration and the more sand will it be able to cement together. A number of well known investigations have brought this out so prominently that no further discussion is necessary.

The fineness of the cement is commonly measured by means of sieves, the 100 mesh screen being taken as the standard. Not more than 5 per cent. of the weight of the cement should be retained by the sieve, the wire being No. 40 of Stubbs' wire gauge. Finer sieves than the 150 mesh are not satisfactory for dry sieving, as they invariably tend to clog and give unreliable results. If they are to be used the cement should be put through wet, that is, made up into a thin paste with alcohol. In the nature of the case sieves cannot afford an accurate means of separating the really fine dust in a cement. This must be accomplished by means of the so-called mechanical analysis described at length in previous paragraphs.

Other means have also been suggested, like the separation by a current of air blown through a conical vessel, at a definite pressure, the current of air being conducted through a central pipe nearly to the bottom of the vessel. The fine particles are caught in a large cylinder. The air pressure is equal to a water column 3 inches high. The fine flour thus removed from commercial cements was found to be about 50 per cent. By increasing or reducing the pressure various sizes can be separated. An apparatus of this kind was proposed by W. F. Goreham.

SOME PHYSICAL AND CHEMICAL CONSTANTS.

The coefficient of expansion of pure Portland Cement is not of as great practical importance as that of the cement mortar or concrete. It is evident, of course, that the coefficient is somewhat influenced by the character of the aggregate in concrete. The coefficient of expansion of Portland cement, between 8° and 70° C. was found to be, by C. H. Au, 0.0000115 per degree C.

Bouhceau found the coefficient of expansion of concrete to be 0.0000137, that of wrought iron 0.00001235. This explains why reinforced concrete does not give rise to difficulties due to the differences in the coefficients of expansion, the expansion values of the concrete and iron being nearly the same. It might be mentioned here, also, that in reinforced concrete, according to the work of Considere, the tensile strength obtained approaches very closely that of the iron employed and cracking appears only when the tensile strains approach the elastic limit of the iron.

The specific heat of Portland cement clinker was found by Dr. Hart to be 0.19. The heat of hydration of a number of commercial Portland cements in excess of water was found to be not more than 8 calories per gram. In regard to the heat of solution of cements in acid, and other data, Meyer has worked out the following results. In this work he employed three cements of the following composition:

	Silica. Per cent.	Alumina. Per cent.	Ferrie Oxide. Per cent.	Lime. Per cent.	Magnesia. Per cent.
A.....	23.2	11.4	2.5	61.5	2.7
B.....	22.1	9.7	2.4	63.3	2.4
C.....	20.9	8.8	2.2	65.5	2.3

These cements were burnt at different temperatures and tested for specific gravity, alkalinity, constancy in volume and heat of solution.

Cement.	Burning tempera- ture in Seger cones.	Specific gravity.	Alkalinity accord- ing to Fresenius.	Boiling test.	Heat of solution calories.	Expansion of 10 cm. prism, in per cent.			
						In days.			
						3	7	28	90
A	12	3.243	6.6	friable	447	0.060	0.100	0.320	0.440
do	15	3.139	6.0	do	442	0.010	0.020	0.100	0.100
do	18	3.216	4.9	harder	447	0.025	0.050	0.120	0.180
do	21	3.159	5.6	hard	458	0.010	0.010	0.010	0.025
B	12	3.178	8.5	friable	470	0.010	0.025	0.065	0.125
do	15	3.199	6.5	hard	440	0.005	0.015	0.045	0.050
do	18	3.195	4.4	good	471	0.015	0.020	0.035	0.035
do	21	3.160	5.1	good	529	....	....	....	0.015
C	12	3.166	11.1	broke down	525	0.040	0.090	0.500	1.520
do	15	3.200	9.6	broke down	577	0.025	0.060	0.150	0.420
do	18	3.230	8.6	very friable	542	0.060	0.100	0.250	0.450
do	21	3.170	7.0	very friable	517	0.125	0.125	0.420	0.850

The "alkalinity" means the number of cc. of deci-normal acid used in neutralizing 50 cc. of distilled water which was in contact with 0.5 gram of cement.

Other physical and chemical constants determined by Dr. R. and Dr. W. Fresenius are given in the following table.*

Description.	1 Specific gravity.	2 Loss on ignition. Per cent.	3 Alkalinity imparted to water by 0.5 gram, cc. of decinormal acid.	4 Volume of normal acid neutralized by 1 gram.	5 Weight of KMnO_4 reduced by 1 gram.	Weight of CO_2 absorbed by 3 grams.
				cc.	mg.	mg.
Portland cement A	3.155	1.58	6.25	20.71	0.79	1.4
“ “ B	3.125	2.59	4.62	21.50	2.38	1.6
“ “ C	3.155	2.11	4.50	20.28	0.93	1.8
“ “ D	3.144	1.98	5.10	21.67	1.12	1.0
“ “ E	3.144	1.25	6.12	19.60	0.98	1.6
“ “ F	3.134	2.04	4.95	20.72	1.21	1.1
“ “ G	3.144	0.71	4.30	22.20	0.89	0.0
“ “ H	3.125	1.11	4.29	20.30	1.07	0.7
“ “ J	3.134	1.00	4.00	19.40	2.01	0.0
“ “ K	3.144	0.34	4.21	20.70	0.98	0.0
“ “ L	3.154	1.49	4.60	18.80	2.80	0.3
“ “ M	3.125	1.25	5.50	20.70	2.33	0.0

EFFECT OF VARIOUS REAGENTS ON PORTLAND CEMENT.

Since Portland cement is a very basic material, it is quite evident that it is readily attacked by acids and we find that even weak organic acids may exert a powerful solvent action upon this material. When mixed with sand, however, and especially if the resulting mortar is dense, the action is much less evident than on the neat cement. Even carbonic acid, carbon dioxide in solution in water, is able to act upon cement quite strikingly. On the other hand, salts show varying effects, as will be illustrated by a table. In common with colloids, hydrated cement has the property of taking salts from solution and of holding them by virtue of surface absorption, so that the concentration of such salts is greater in the colloid (hydrogel) than in the solution.

Gases like carbon dioxide, hydrogen sulphide, act upon cement quite energetically. Thus Tetmayer found that by storing four cements in air and in pure carbon dioxide the average tensile strength of

*R. K. Meade, *Examination of Portland Cement*, p. 167.

1:3 mortars was 29.4 kg. per square cm. for the cements stored in air and 45.3 kg. per square cm. for the cements exposed to pure carbon dioxide. The effect of moist air on cement is not as injurious as is often supposed. Sewage was found to have practically no effect upon standard cement mortar. Tar and mineral oils do not act upon cement; organic oils and the tannic acids form soaps with the lime of the cement which tend to soften the latter. This action, however, owing to surface incrustation, is of little importance in practical work. Of the materials added to cement for coloring purposes, like pyrolusite for black, iron or ochre for red and yellow, ultramarines for blue and green, only the latter do not decrease the ultimate strength. Ultramarine, in fact, has a strong tendency to increase the strength due to pozzuolanic action. Owing to the basic character of cements and the content of sulphates and alkalies, a number of minor reactions take place with the coloring constituents. Thus iron ore is in part attacked by the lime and bleached, as may be observed on the hollow blocks now used to so large an extent, the pyrolusite likewise is attacked and made, in part, soluble, while the ultramarine is decomposed in a comparatively short time, since its sulphur is removed by the lime of the cement. As the sulphides seem necessary for the color, on decomposition of the compound, $2(\text{Na}_2\text{Al}_2\text{Si}_3\text{O}_{10}) + \text{Na}_2\text{S}_4$, the color must, of course, disappear. The addition of ground white marble does not help much in retaining these colors, but the grinding together of cement and white quartz, or white anhydrous silicates, would result in far greater permanency. Likewise the colors could be made permanent in themselves by being prepared as silicates. It seems to the writer that the Portland cement manufacturers should cater to this demand for prepared cement as well as to the production of white cements. The addition of such silicious matter would also tend to increase the durability of cement work in a most decided manner and would help remove the prejudice, justified in many cases, against architectural cement surfaces.

In the table on page 364, the effects of a number of salts upon the strength of Portland cement are shown:

It is true that many cements are apparently improved by the addition of gypsum in small amounts, but it has also been found that high grade cements show practically no improvement. Dr. Erdmenger's work proves quite strikingly that the gypsum is a source of weakness which should be kept within the lowest possible limit.

THE ENDURING QUALITIES OF PORTLAND CEMENT.

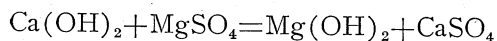
As has already been indicated, Portland cement, like all basic hydrous rocks, is subject to rather rapid destruction by atmospheric agencies if exposed without the addition of sand. It has also been found that

Erdmenger's Table Showing Effect of Various Salts on the Behavior of Portland Cements.

Substance added.	Time of setting minutes.			Tensile strength neat, 28 days, kg. per sq. cm.			Tensile strength 1:3, 28 days, kg. per sq. cm.		
Cement alone ..	10 minutes.			40.8			13.3		
Per cent added.	1%	2%	5%	1%	2%	5%	1%	2%	5%
Raw gypsum...	240	360	360	56.5	62.6	26.4	19.9	....	....
Potass. sulphate	4	2	5	41.3	35.2	34.2	16.7	13.8	....
Sodium sulph'te	15	5	5	43.2	46.0	43.2	19.4	19.0	....
Ammon sulph..	120	300	480	54.4	35.3	....	15.1	....	....
Magnes. sulph.	15	480	24 hrs.	48.1	37.1	46.3	15.5	14.3	....
Alumin. sulph.	15	10	30	40.0	40.0	34.3	16.4	16.7	....
Iron sulphate..	360	720	240	48.0	41.9	34.5	15.9	....	....
Alum.....	10	30	40	41.7	40.7	....	14.9	....	....
Caustic potash.	....	3	.....	....	29.4	....	....	15.1	....
Ammonium.... hydroxide....	....	3	.....	....	46.8	....	....	17.5	....

some Portland cement mortars were destroyed at an alarming rate in sea water, and consequently a vast mass of literature exists on this point and the data collected are exceedingly contradictory and confusing. However, thanks to the work of the German Portland Cement Manufacturers' Association, some light has been thrown on the action of sea water, and though the experiments carried on by this society on a large scale are not yet finished, it is known now that there is little danger for sea water work if the mortar is made dense and good Portland cement is used.

The supposed destruction of Portland cement concrete is said to be due to the magnesium content of sea water and formation of calcium-aluminum sulphates. The alumina is said to be especially injurious and gypsum also is a source of danger in this respect. Rebuffat ascribes the partial solution of the cement to the formation of sulfo-aluminates. Michaelis and Vicat think that the action is based on the reaction:



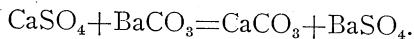
which, owing to the formation of crystalline calcium sulphate, causes an

increase in volume and thus destroys the mortar. A number of other investigators have attacked the problem like Chatelier, Debray, Feret, Deval and others. The results may be summarized by saying that the alumina and gypsum are the weak points of the cement while the ferric oxide is beneficial. The cements should be as silicious and as high in ferric oxide as possible.

Addition of Pozzuolane.—Michaelis, Sr., has also shown that the resistance of Portland cement to sea water may be increased enormously by the addition of pozzuolanic material, like trass. If trass or a similar material is not available, there is no reason whatever why well burnt clay may not be used; in fact, the writer has found that just as natural cements are improved by the addition of slaked lime, the reaction may be reversed in the case of the basic Portland cements by adding pozzuolanic material or ground burnt clay. Thus we increase the resulting strength by the addition of a secondary hydraulic reaction and obtain as the resulting strength the initial strength of the Portland cement plus the strength derived from the secondary, pozzuolanic action. In addition, by virtue of the secondary reaction, the resistance of the cement to all kinds of influence is increased by the more silicious character of the mortar. This idea has been carried out in the production of the so-called sand cement, which is simply ordinary Portland cement ground together with trass or sand, and is sold for sea water work. The writer has seen such a plant at Staten Island and another one is reported to be at Chicago. In one of these plants, however, the chemical principle underlying their process was not understood, for in place of the sand, limestone was used because it was easier to grind. This evidently could not improve the cement in the desired direction, though an increase in tensile strength might be observed, independent of any pozzuolanic action, due simply to the second grinding of the cement.

It would be interesting to observe cement work in which the cement was ground together with well burnt clay under adverse conditions, that is, exposed to water containing carbonic acid or any water of acid reaction. Experiments conducted by the writer on a small scale in which cement was ground together in a ball-mill with burnt clay in the proportion of 1:1 showed a much greater resistance to the action of acidulated water (hydrochloric) than cement mortar not so treated. But the laboratory results of such experiments are, as a rule, not comparable with the practical results. If, however, practice should confirm this suggestion, the durability of exposed cement surfaces, of reservoir walls, sea walls, piers, cement blocks would thus be improved cheaply and satisfactorily. It should be the task of Portland cement manufacturers to study these questions and to prepare for the market cements especially suitable for exposed work. Much of the lack of confidence which has existed in certain quarters in years past in the use of cement would thus be eliminated.

Efflorescence.—A great source of annoyance is frequently the appearance of soluble salts on the surface of cement work, giving rise to disagreeable patches of so-called "whitewash." These salts are principally sulphates of the alkalis, lime, magnesia and iron, and can to a large extent be prevented by the addition of fine barium carbonate to the mortar, which takes up the available sulphuric acid and forms the insoluble barium sulphate according to the reaction:



Excess of the barium carbonate should be used. The barium chloride is more efficient, a smaller amount being sufficient owing to its solubility in water, but any excess will in itself produce a white efflorescence. For decorative purposes cement with a silicious clay base free from gypsum should be used.

Another method of preventing efflorescence is the application of a solution of silicon fluoride of magnesium or lead. This solution reacts with the lime of the cement forming an insoluble double silicon fluoride.

Dr. Michaelis* advocates the use of a dilute water glass solution which is applied several times and finally the surface is washed thoroughly with water to remove the alkalis which have become free by the combination of the silicic acid with the lime.

For preparing a cement surface for painting Dr. Fruehling** recommends an ammonium carbonate solution applied upon the hardened cement.

Adulteration.—Sometimes it is found that Portland cement is adulterated with ground slag and it becomes necessary to detect the presence of the latter, or again natural cement may be the adulterant. Such constituents may be detected by means of the following differentiation:

1. Portland cement has a higher specific gravity than either the natural cement or slag.
2. The loss on ignition of natural cement is much greater than that of Portland cement.
3. The amount of carbon dioxide absorbed by natural cement may be greater than that taken up by Portland cement.
4. Owing to the high content of sulphides in slag the amount of potassium permanganate decolorized by slag is much greater than that consumed by Portland cement, and of course the amount of sulphide sulphur is much larger in amount.

Mechanical Separation.—The difference in specific gravity is employed to separate the admixed substances from the Portland cement. This is carried out as follows: By means of the 20, 30 and 40 mesh

*Dr. Michaelis, *Die Hydraulischen Moertel*, 313.

**Polytech, *Centralblatt*, 1871, p. 261.

sieves two sizes of grain, a and b, are separated and carefully dried. Of each size 5 grams are taken and shaken in a dry Haradas separatory funnel with a mixture of methyl iodide and purified oil of turpentine. This mixture should have at 15° C. a specific gravity of 3.01. The methyl iodide before being used should be dried over calcium chloride and filtered through previously ignited Portland cement. A hydrometer may be used for determining the specific gravity of the liquid. A suction pump is now attached to the funnel and the particles are separated according to whether they are lighter or heavier than 3.01.

The light particles which float are:

1. Coal, mean specific gravity, 1.39.
2. Gypsum, mean specific gravity, 2.33.
3. Coal cinders, mean specific gravity, 2.73.
4. Natural cement, mean specific gravity, 2.60.
5. Blast furnace slag, mean specific gravity, 2.94.

The heavier particles which sink are:

1. Portland cement, mean specific gravity, 3.10.
2. Particles of slag, high in iron, or particles of metallic iron.

In unadulterated Portland cement the amount of light material is small and hence any large amount of matter floating in the liquid is to be regarded as suspicious. Chemical analysis, including the determination of sulphide sulphur, will show whether the light material is natural cement or slag. In both cases the separated particles will analyze much lower in lime than the Portland cement. The presence of sulphide will indicate that the inert matter is slag.

In the following table some of the characteristics of natural cement and slag are indicated:*

Description.	Specific gravity.	Loss on ignition. Per cent.	Alkalinity imparted to water by 0.5 gram.	Volume of normal acid neutralized by 1 gram. In c.c.	Weight of potas- sium permang. reduced by 1 gram. In mg's.	Weight of carbon dioxide ab- sorbed by 3 grams. In mg's.
			cc. of deci- normal acid.			
Hydraulic lime A..	2.441	18.26	20.23	21.35	1.40	27.8
" " B..	2.551	17.82	22.73	26.80	0.93	31.3
" " C..	2.520	19.60	19.72	19.96	0.98	47.7
Weathered slag A..	3.012	0.76	0.91	14.19	74.60	3.6
" " B..	3.003	1.92	0.70	13.67	60.67	3.5
" " C..	2.967	1.11	1.00	9.70	44.34	2.9
Ground slag D..	3.003	0.32	0.31	3.60	64.40	2.4
" " E..	2.873	0.43	0.11	8.20	73.27	2.2

*Meade, *Examination of Portland Cement.*

CEMENT SPECIFICATIONS.

In the following paragraphs the rules proposed by a committee of the American Society of Civil Engineers for the testing of Portland cement are given which were submitted to the society, January, 1903:

On several matters which have been considered, such as the substitution of a natural sand for the standard quartz, and the tests for the normal consistency and constancy of volume, the committee has not reached final conclusions.

SAMPLING.

1. **Selection of Sample.**—The selection of the sample for testing is a detail that must be left to the discretion of the engineer; the number and the quantity to be taken from each package will depend largely on the importance of the work, the number of tests to be made and the facilities for making them.

2. The sample shall be a fair average of the contents of the package; it is recommended that, where conditions permit, one barrel in every ten be sampled.

3. All samples should be passed through a sieve having twenty meshes per linear inch, in order to break up lumps and remove foreign material; this is also a very effective method for mixing them together in order to obtain an average. For determining the characteristics of a shipment of cement, the individual samples may be mixed and the average tested; where time will permit, however, it is recommended that they be tested separately.

4. **Method of Sampling.**—Cement in barrels should be sampled through a hole made in the center of one of the staves, midway between the heads, or in the head, by means of an auger or a sampling iron similar to that used by sugar inspectors. If in bags, it should be taken from surface to center.

CHEMICAL ANALYSIS.

5. **Significancc.**—Chemical analysis may render valuable service in the detection of adulteration of cement with considerable amount of inert material, such as slag or ground limestone. It is of use, also, in determining whether certain constituents, believed to be harmful when in excess of a certain percentage, as magnesia and sulphuric anhydride, are present in inadmissible proportions. While not recommending a definite limit for these impurities, the committee would suggest that the most recent and reliable evidence appears to indicate that magnesia to the amount of 5 per cent. and sulphuric anhydride to the amount of 1.75 per cent. may safely be considered harmless.

6. The determination of the principal constituents of cement, silica, alumina, iron oxide and lime is not conclusive as an indication of quality. Faulty character of cement results more frequently from imperfect preparation of the raw material or defective burning than from incorrect pro-

portions of the constituents. Cement made from very finely-ground material, and thoroughly burned, may contain much more lime than the amount usually present and still be perfectly sound. On the other hand, cement low in lime may, on account of careless preparation of the raw material, be of dangerous character. Further, the ash of the fuel used in burning may so greatly modify the composition of the product as largely to destroy the significance of the results of analysis.

7. Method.—As a method to be followed for the analysis of cement, that proposed by the committee on uniformity in the analysis of materials for the Portland cement industry, of the New York section of the Society for Chemical Industry, and published in the *Journal of the Society* for January 15, 1902, is recommended.

SPECIFIC GRAVITY.

8. Significance.—The specific gravity of cement is lowered by underburning, adulteration and hydration, but the adulteration must be in considerable quantity to affect the results appreciably.

9. Inasmuch as the differences in specific gravity are usually very small, great care must be exercised in making the determination.

10. When properly made, this test affords a quick check for underburning or adulteration.

11. Apparatus and Method.—The determination of specific gravity is most conveniently made with Le Chatelier's apparatus. This consists of a flask (D) (figure 78) of 120 cu.cm. (72.32 cu. in.) capacity, the neck of which is about 2 cm. (7.87 in.) long; in the middle of the neck is a bulb (C), above and below which are two marks (F) and (E); the volume between these marks is 20 cu. cm. (1.22 cu. in.). The neck has a diameter of about 9 mm. (0.35 in.), and is graduated into tenths of cubic centimeters above the bulb.

12. Benzine (62° Baume) naptha, or kerosene free from water, should be used in making the determination.

13. The specific gravity can be determined in two ways:

(1.) The flask is filled with either of these liquids to the lower mark (E), and 64 gr. (2.25 oz.) of powder, previously dried at 100° C. (212° F.) and cooled to the temperature of this liquid, is gradually introduced through the funnel (B) the stem of which extends into the flask to the top of the bulb (C), until the upper mark (F) is reached. The difference in weight between the cement remaining and the original quantity (64 gr.) is the weight which has displaced 20 cu. cm.

14. (2) The whole quantity of the powder is introduced, and the level of the liquid rises to some division of the graduated neck. This reading plus 20 cu. cm. is the volume displaced by 64 gr. of the powder.

15. The specific gravity is then obtained from the formula:

$$\text{Specific Gravity} = \frac{\text{Weight of Cement}}{\text{Displaced Volume}}$$

16. The flask, during the operation, is kept immersed in water in a jar (A), in order to avoid variations in the temperature of the liquid. Duplicate results should agree to 0.01.

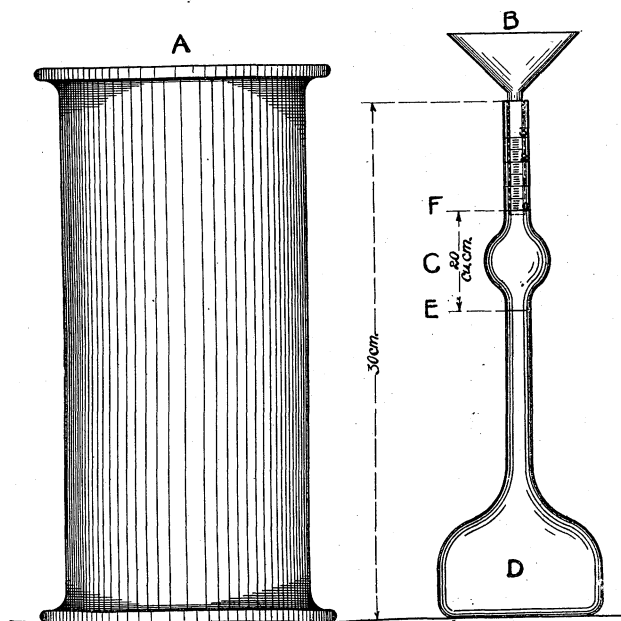


Fig. 78. Specific gravity apparatus, according to Le Chatelier.

17. A convenient method for cleaning the apparatus is as follows: The flask is inverted over a large vessel, preferably a glass jar, and shaken vertically until the liquid starts to flow freely; it is then held still in a vertical position until empty; the remaining traces of cement can be removed in a similar manner by pouring into the flask a small quantity of clean liquid and repeating the operation.

18. More accurate determinations may be made with the pincometer.

FINENESS.

19. **Significance.**—It is generally accepted that the coarser particles in cement are practically inert, and it is only the extremely fine powder that possesses adhesive or cementing qualities. The more finely cement is pulverized, all other conditions being the same, the more sand it will carry and produce a mortar of a given strength.

20. The degree of final pulverization which the cement received at the place of manufacture is ascertained by measuring the residue retained

on certain sieves. Those known as the No. 100 and No. 200 sieves are recommended for this purpose.

21. Apparatus.—The sieves should be circular, about 20 cm. (7.87 in.) in diameter, 6 cm. (2.36 in.) high, and provided with a pan, 5 cm. (1.97 in.) deep, and a cover.

22. The wire cloth should be woven (not twilled) from brass wire having the following diameters:

No. 100, 0.0045 in.; No. 200, 0.0024 in.

23. This cloth should be mounted on the frames without distortion; the mesh should be regular in spacing and be within the following limits:

No. 100, 96 to 100 meshes to the linear inch.

No. 200, 188 to 200 meshes to the linear inch.

24. Fifty grams (1.76 oz.) or 100 gr. (3.52 oz.) should be used for the test and dried at a temperature of 100° C. (212° F.) prior to sieving.

25. Method.—The committee, after careful investigation, has reached the conclusion that mechanical sieving is not as practicable or efficient as hand work, and, therefore, recommends the following method:

26. The thoroughly dried and coarsely screened sample is weighed and placed on the No. 200 sieve, which, with pan and cover attached, is held in one hand in a slightly inclined position, and moved forward and backward, at the same time striking the side gently with the palm of the other hand, at the rate of about 200 strokes per minute. The operation is continued until not more than one-tenth of one per cent. passes through after one minute of continuous sieving. The residue is weighed, then placed on the No. 100 sieve and the operation repeated. The work may be expedited by placing in the sieve a small quantity of large shot. The results should be reported to the nearest tenth of 1 per cent.

NORMAL CONSISTENCY.

27. Significance.—The use of a proper percentage of water in making the pastes* from which pats, tests of setting and briquettes are made, is exceedingly important, and affects vitally the results obtained.

28. The determination consists in measuring the amount of water required to reduce the cement to a given state of plasticity, or to what is usually designated normal consistency.

29. Various methods have been proposed for making this determination, none of which have been found entirely satisfactory. The committee recommends the following:

30. Method. Vicat Needle Apparatus.—This consists of a frame (K), (Figure 79) bearing a movable rod (L), with the cap (A) at one

*The term "paste" is used in this report to designate a mixture of cement and water, and the word "mortar" a mixture of cement, sand and water.

end, and at the other end the cylinder (B), 1 cm. (0.39 in.) in diameter, the cap, rod and cylinder weighing 300 gr. (10.58 oz.). The rod, which can be held in any desired position by a screw (F) carries an indicator,

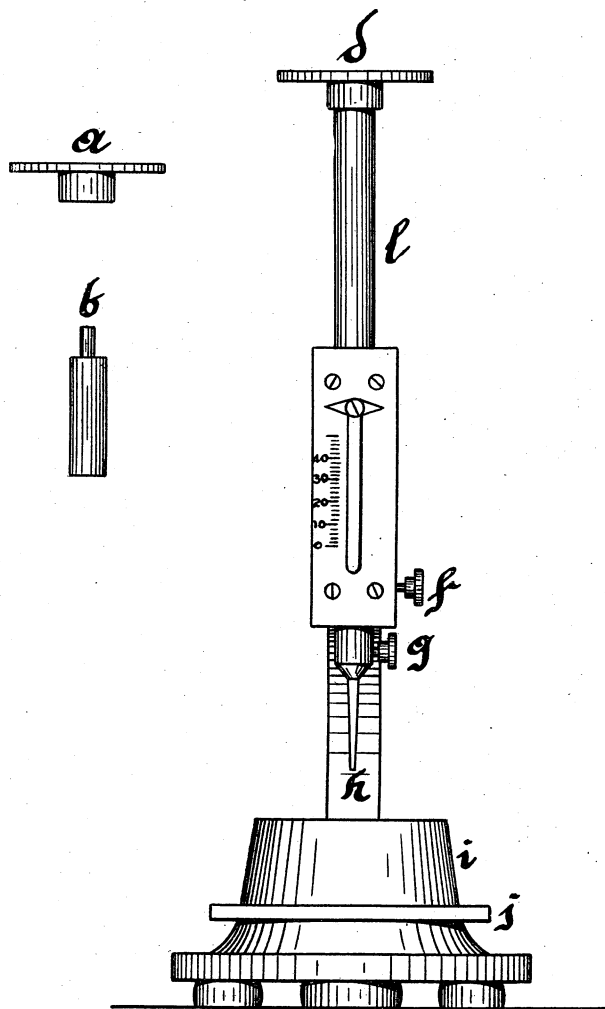


Fig. 79. Vicat's needle for measuring standard consistency of cement mortars, and also detecting moment of initial hardening.

which moves over a scale (graduated to millimeters) attached to the frame (K). The paste is held by a conical, hard-rubber ring (I), 7 cm. (2.76 in.) in diameter at the base, 4 cm. (1.57 in.) high, resting on a glass plate (J), about 10 cm. (3.94 in.) square.

31. In making the determination, 500 gr. (17.64 oz.) of cement are kneaded into a paste, as described in paragraph 58, and quickly formed into a ball with the hands, completing the operation by tossing

it six times from one hand to the other, maintained 6 inches apart; the ball is then pressed into the rubber ring, through the larger opening, smoothed off, and placed on a glass plate (on its large end) and the smaller end smoothed off with a trowel; the paste, confined in the ring, resting on the plate, is placed under the rod bearing the cylinder, which is brought in contact with the surface and quickly released.

32. The paste is of normal consistency when the cylinder penetrates to a point in the mass 10 mm. (0.39 in.) below the top of the ring. Great care must be taken to fill the ring exactly to the top.

33. The trial pastes are made with varying percentages of water until the correct consistency is obtained.

34. The committee believes that the normal consistency should produce a rather wet paste, since this consistency tends to greater uniformity in the mixing, and there is less liability of compressing the briquettes during the molding.

35. Having determined in this manner the proper percentage of water required to produce a neat paste of normal consistency, the proper percentage required for the sand mortars is obtained from an empirical formula.

36. The committee hopes to devise such a formula. The subject proves to be a very difficult one, and, although the committee has given it much study, it is not yet prepared to make a definite recommendation.

TIME OF SETTING.

37. **Significance.**—The object of this test is to determine the time which elapses from the moment water is added until the paste ceases to be fluid and plastic (called the "initial set"), and also the time required for it to acquire a certain degree of hardness (called the "final" or "hard set"). The former of these is the more important, since, with the commencement of setting, the process of crystallization or hardening is said to begin. As a disturbance of this process may produce a loss of strength, it is desirable to complete the operation of mixing and molding or incorporating the mortar into the work before the cement begins to set.

38. It is usual to measure arbitrarily the beginning and end of the setting by the penetration of weighted wires of given diameters.

39. **Method.**—For this purpose the Vicat needle, which has already been described in paragraph 30, should be used.

40. In making the test, a paste of normal consistency is molded and placed under the rod (L) (figure 79), as described in paragraph 31; this rod, bearing the cap (D) at one end and the needle (H), 1 mm. (0.039 in.) in diameter at the other, weighing 300 gr. (10.58 oz.). The needle is then carefully brought in contact with the surface of the paste and quickly released.

41. The setting is said to have commenced when the needle ceases to pass a point 5 mm. (0.20 in.) above the upper surface of the glass plate, and is said to have terminated the moment the needle does not sink visibly into the mass.

42. The test pieces should be stored in moist air during the test; this is accomplished by placing them on a rack over water contained in a pan and covered with a damp cloth, the cloth to be kept away from them by means of a wire screen; or they may be stored in a moist box or closet.

43. Care should be taken to keep the needle clean, as the collection of cement on the sides of the needle retards the penetration, while cement on the point reduces the area and tends to increase the penetration.

44. The determination of the time of setting is only approximate, being materially affected by the temperature of the mixing water, the temperature and humidity of the air during the test, the percentage of water used, and the amount of molding the paste receives.

STANDARD SAND.

45. The committee recognizes the grave objections to the standard quartz now generally used, especially on account of its high percentage of voids, the difficulty of compacting in the molds, and its lack of uniformity; it has spent much time in investigating the various natural sands which appeared to be available and suitable for use.

46. For the present the committee recommends the natural sand from Ottawa, Ill., screened to pass a sieve having 20 meshes per linear inch and retained on a sieve having 30 meshes per linear inch; the wires to have diameters of 0.0165 and 0.0112 inch, respectively, i. e., half the width of the opening in each case.

47. The Sandusky Portland Cement Company, of Sandusky, Ohio, has agreed to undertake the preparation of this sand, and to furnish it at a price only sufficient to cover the actual cost of preparation.

FORM OF BRIQUETTE.

48. While the form of a briquette recommended by a former committee of the society is not wholly satisfactory, this committee is not prepared to suggest any change, other than rounding off the corners by curves of $\frac{1}{2}$ inch radius (figure 80).

MOLDS.

49. The molds should be made of brass, bronze or some equally non-corrodible material, having sufficient metal in the sides to prevent spreading during molding.

50. Gang molds, which permit molding a number of briquettes at one time, are preferred by many to single molds, since the greater quantity

of mortar that can be mixed tends to produce greater uniformity in the results.

51. The molds should be wiped with an oily cloth before using.
52. All proportions should be stated by weight; the quantity of water to be used should be stated as a percentage of the dry material.
53. The metric system is recommended because of the convenient relation of the gram and the cubic centimeter.

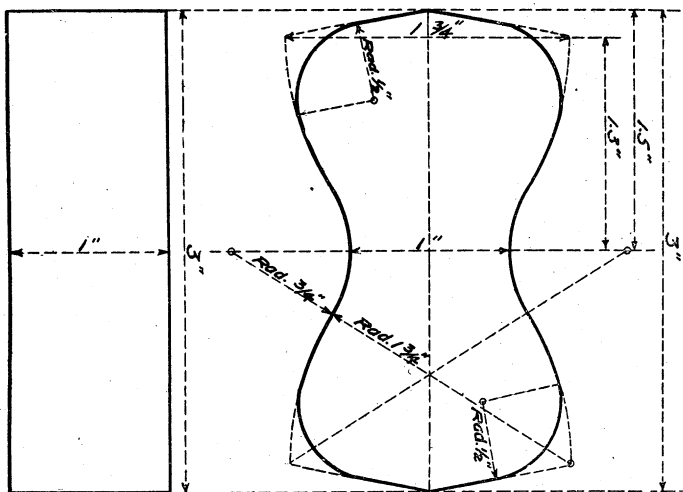


Fig. 80. Standard form of brickette for tensile strength.

54. The temperature of the room and the mixing water should be as near 21° C. (70° F.) as it is practicable to maintain it.

55. The sand and cement should be thoroughly mixed dry. The mixing should be done on some non-absorbing surface, preferably plate glass. If the mixing must be done on an absorbing surface it should be thoroughly dampened prior to use.

56. The quantity of material to be mixed at one time depends on the number of test pieces to be made; about 1,000 gr. (35.28 oz.) makes a convenient quantity to mix, especially by hand methods.

57. The committee, after investigation of the various mechanical mixing machines, has decided not to recommend any machine that has thus far been devised, for the following reasons: (1) The tendency of most cement is to "ball up" in the machine, thereby preventing the working of it into a homogeneous paste; (2) There are no means of ascertaining when the mixing is complete without stopping the machine, and (3) the difficulty of keeping the machine clean.

58. **Method.**—The material is weighed and placed on the mixing table, and a crater formed in the center, into which the proper percentage

of water is poured; the material on the outer edge is turned into the crater by the aid of a trowel. As soon as the water has been absorbed, which should not require more than one minute, the operation is completed by vigorously kneading with the hands for an additional $1\frac{1}{2}$ minutes, the process being similar to that used in kneading dough. A sand-glass affords a convenient guide for the time of kneading. During the operation of mixing, the hands should be protected by gloves, preferably of rubber.

MOLDING.

59. Having worked the paste or mortar to the proper consistency, it is at once placed in the molds by hand.

60. The committee has been unable to secure satisfactory results with the present molding machines; the operation of machine molding is very slow, and the present types permit of molding but one briquette at a time, and are not practicable with the pastes or mortars herein recommended.

61. Method.—The molds should be filled at once, the materials pressed in firmly with the fingers and smoothed off with a trowel without ramming; the material should be heaped up on the upper surface of the mold, and, in smoothing off, the trowel should be drawn over the mold in such a manner as to exert a moderate pressure on the excess material. The mold should be turned over and the operation repeated.

62. A check upon the uniformity of the mixing and molding is afforded by weighing the briquettes just prior to immersion, or upon removal from the moist closet. Briquettes which vary in weight more than 3 per cent. from the average should not be tested.

STORAGE OF THE TEST PIECES.

63. During the first 24 hours after molding, the test pieces should be kept in moist air to prevent them from drying out.

64. A moist closet or chamber is so easily devised that the use of the damp cloth should be abandoned if possible. Covering the test pieces with damp cloth is objectionable, as commonly used, because the cloth may dry out unequally, and, in consequence, all the test pieces are not maintained under the same condition. Where a moist closet is not available, a cloth may be used and kept uniformly wet by immersing the ends in water. It should be kept from direct contact with the test pieces by means of a wire screen or some similar arrangement.

65. The moist closet consists of a soapstone or slate box, or a metal-lined wooden box—the metal lining being covered with felt and this felt kept wet. The bottom of the box is so constructed as to hold water, and the sides are provided with cleats for holding glass shelves on which to place the briquettes. Care should be taken to keep the air in the closet uniformly moist.

66. After 24 hours in moist air, the test pieces for longer periods of time should be immersed in water maintained as near 21° C. (70° F.) as practicable; they may be stored in tanks or pans, which should be of non-corrodable materials.

TENSILE STRENGTH.

67. The tests may be made on any standard machine. A solid metal clip, as shown in figure 81, is recommended. The clip is to be used without cushioning at the points of contact with the test specimen. The bearing at each point of contact should be $\frac{1}{4}$ inch wide, and the distance between the center of contact on the same slip should be $1\frac{1}{4}$ inches.

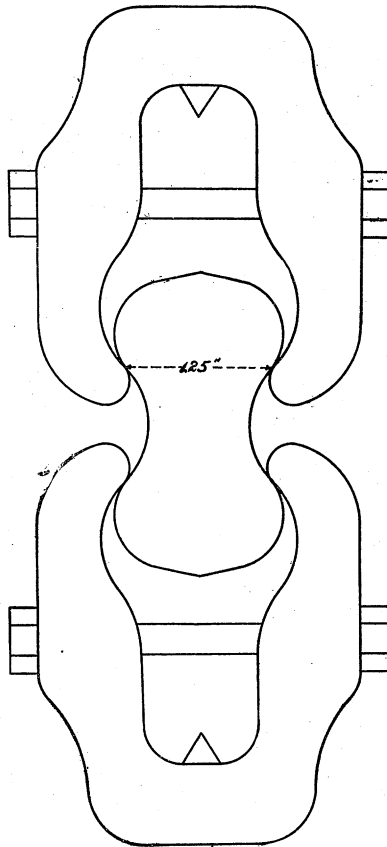


Fig. 81. Standard form of clips for holding tensile test pieces.

68. Test pieces should be broken as soon as they are removed from the water. Care should be observed in centering the briquettes in the testing machine, as cross-strains produced by improper centering tend to lower the breaking strength. The load should not be applied too suddenly, as it may produce vibration, the shock from which often

breaks the briquette before the ultimate strength is reached. Care must be taken that the clips and the sides of the briquettes be clean and free from sand or dirt, which would prevent a good bearing. The load should be applied at the rate of 600 pounds per minute. The average of the briquettes of each sample tested should be taken as the test, excluding any results which are manifestly faulty.

CONSTANCY OF VOLUME.

69. Significance.—The object is to develop those qualities which tend to destroy the strength and durability of a cement. As it is highly essential to determine such qualities at once, tests of this character are for the most part made in a very short time, and are known, therefore, as accelerated tests. Failure is revealed by cracking, checking, swelling or disintegration, or all of these phenomena. A cement which remains perfectly sound is said to be of constant volume.

70. Method.—Tests for constancy of volume are divided into two classes: (1) normal tests, or those made in either air or water maintained at about 21° C. (70° F.) and (2) accelerated tests, or those made in air, steam or water at a temperature of 45° C. (115° F.) and upwards. The test pieces should be allowed to remain 24 hours in moist air before immersion in water or steam.

71. For these tests, pats, about $7\frac{1}{2}$ cm. (2.95 in.) in diameter, $1\frac{1}{4}$ cm. (0.49 in.) thick at the center, and tapering to a thin edge, should be made, upon a clean glass plate (about 10 cm. (3.94 in.) square), from cement paste of normal consistency.

72. Normal Test.—A pat is immersed in water maintained as near 21° C. (70° F.) as possible for 28 days and observed at intervals; the pat should remain firm and hard and show no signs of cracking, distortion or disintegration.

73. Accelerated Test.—(a) A pat is placed on a shelf in a suitable vessel filled with fresh water, but without allowing it to touch the bottom. The water is then gradually raised to a temperature of 45° C. (115° F.) and maintained at this temperature for 24 hours; or (b), a pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel, for 3 hours.

74. To pass these tests satisfactorily, the pats should remain firm and hard, and show no signs of cracking, distortion or disintegration.

75. Should the pat leave the plate, distortion may be detected best with a straight-edge applied to the surface which was in contact with the plate.

76. In the present state of our knowledge it cannot be said that cement should necessarily be condemned simply for failure to pass the accelerated tests; nor can a cement be considered entirely satisfactory simply because it has passed these tests.

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